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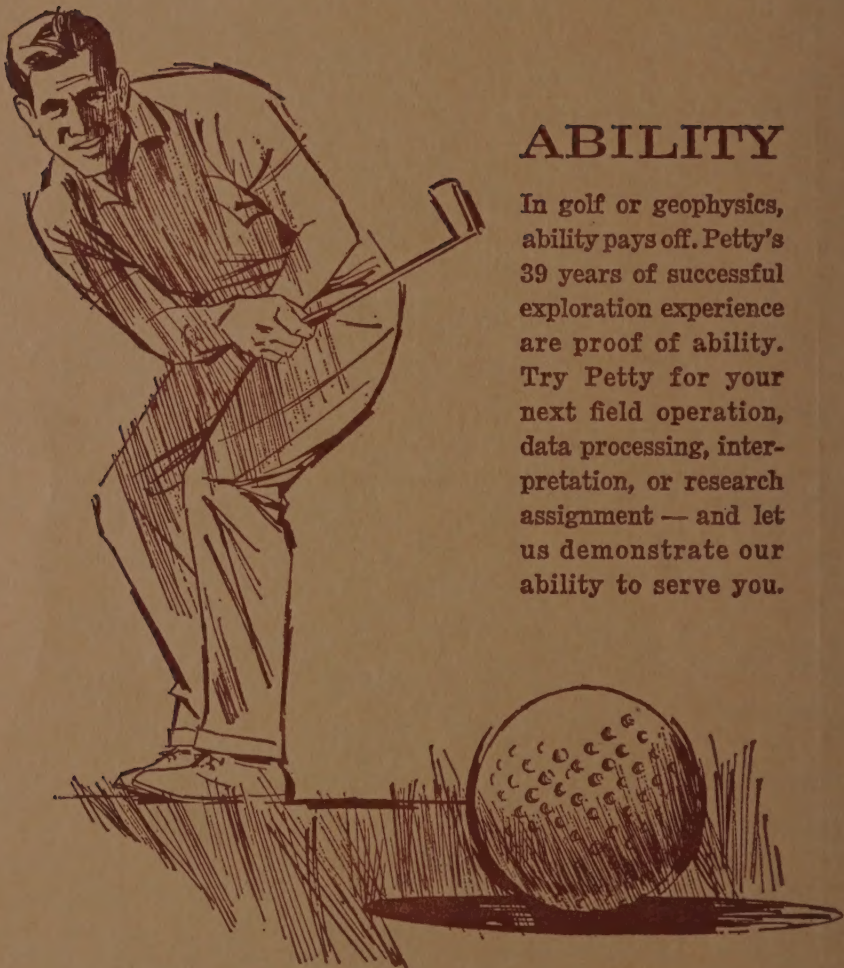
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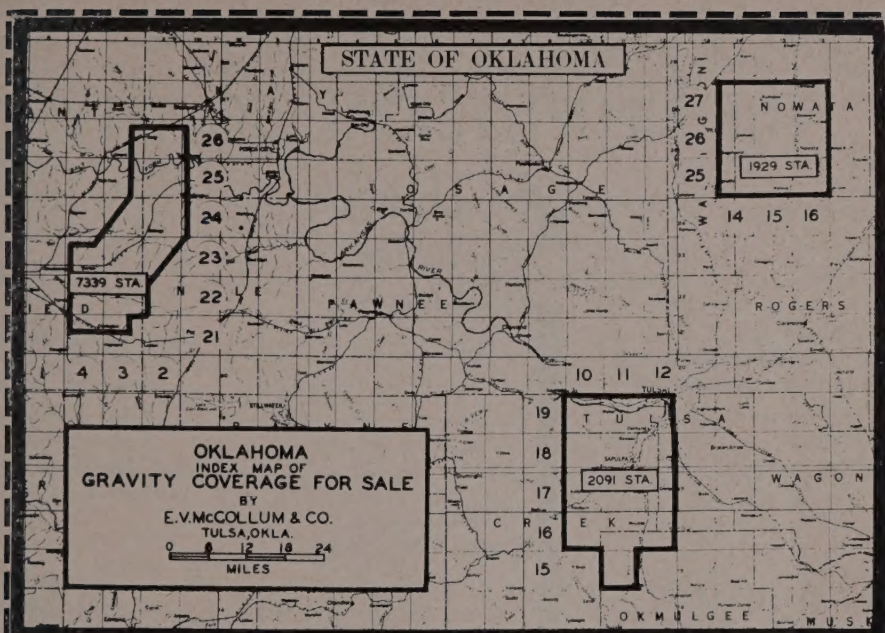


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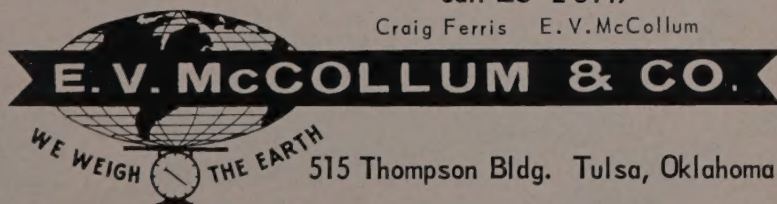
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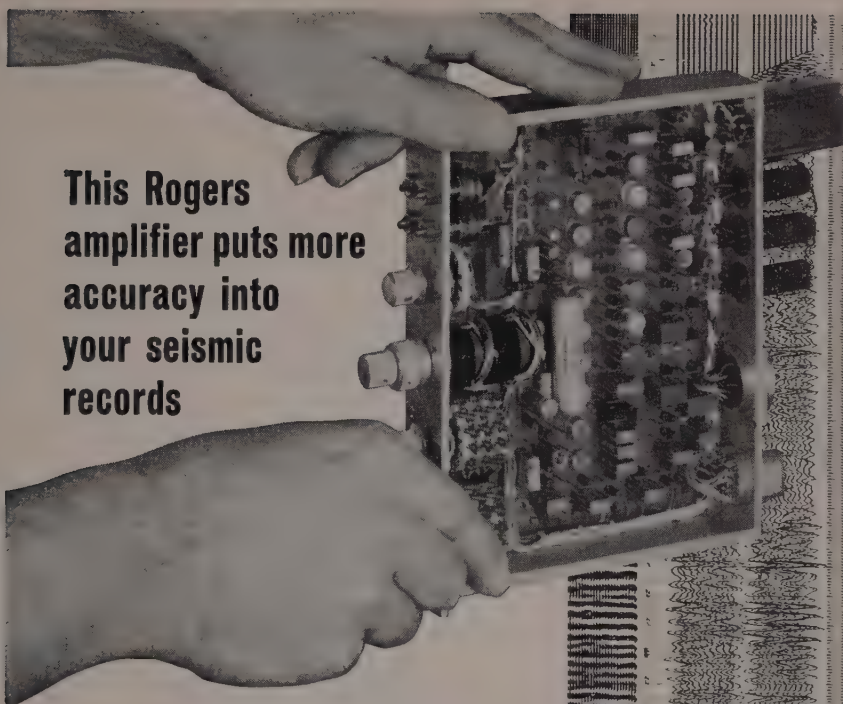
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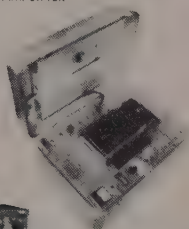
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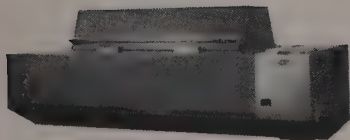
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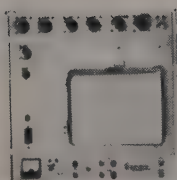
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## EDITORS' FOREWORD

This issue of the Proceedings of the Geophysical Society of Tulsa is for the three-year period 1961-1964.

These brief remarks must rightly begin with acknowledgments of generous collaboration from outside our own Society. The editors sought and received such collaboration on a scale unprecedented for the *Proceedings*. The Oklahoma Geological Survey worked closely and faithfully with us in preparation of the magnetic and gravity compilation maps of the State, which are the central theme of this issue. The Survey performed professional-grade drafting free of charge, handled the printing, and delivered final copies at cost. Dr. Louise Jordan, of the Survey, courageously undertook to describe the regional geology of Oklahoma, a "first" in the geological literature of the State. The valuable end result heads our list of technical articles for this Volume VIII. The Regional Geophysics Branch of the U. S. Geological Survey aided our cause in various ways. Most importantly, they released the data from reconnaissance aeromagnetic coverage flown over northeastern Oklahoma in 1957; these are published here for the first time. The U. S. Coast and Geodetic Survey helpfully provided detailed information on gravity and magnetic base stations, some of it updated for our purposes.

The present compilation geophysical maps of Oklahoma are a beginning, not an end in themselves. The geological interpretations and speculations offered in the papers describing the maps speak at once of what is already understood about the geological significance of regional magnetic and gravity anomalies in the State, and of how much more remains to be comprehended, clarified, or investigated. These "big picture" maps are hardly a vital contribution to petroleum geophysics, especially considering the mature state of geophysical exploration in Oklahoma. It is our hope, however, that these maps may play a role in the planning and elucidation of large-scale seismic studies of the deep crust and beyond, studies pioneered in the State by our own Society four years ago and more recently resumed on a grander scale by Tulsa University's Earth Sciences Department.

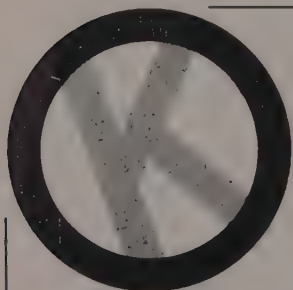
Whither the *Proceedings* of the Geophysical Society of Tulsa? Alone among local geophysical societies our Society attempts to put out a technical journal. The *Proceedings* is not a proper or attractive medium for serious geophysical literature of national and international scope, nor for the tide of research papers by specialists. Authors of such material understandably seek, and deserve, large circulation and greater prestige. What then can and should our product be? We submit that a publication of a local geophysical society

should aim largely for technical material local to state-wide in scope. We hope that Volume VIII will show the way in this direction.

Surely the Society's active membership of some 450 can be tapped for enough worthwhile yet non-competitive geophysical papers to nourish a respectable biennial bulletin. Even this modest response cannot be accomplished without resourceful efforts by the editors working with and through the Executive Committee and the membership of G.S.T. Historically, by all accounts, the *Proceedings* has been a lonesome effort by one or two frantic editors "doing what they could." If this has been the rule, then the present issue has been a happy exception. It is a pleasure to acknowledge the major contributions by G.S.T. members—Messrs. V. L. Jones, Paul L. Lyons, and J. J. Roark—to Volume VIII. Yet unless and until publication of the *Proceedings* can become an established objective and concern of the whole Society, at least on a par with the Annual Picnic, we have more desperate editors and more thin bulletins in our future.

This volume of the *Proceedings* has been a joint production by the Editor and the Editor-Elect. The Editor set the theme for the issue and was primarily responsible for marshalling the editorial material. The Editor-Elect organized other sections of the bulletin and served as unofficial manager of advertising.

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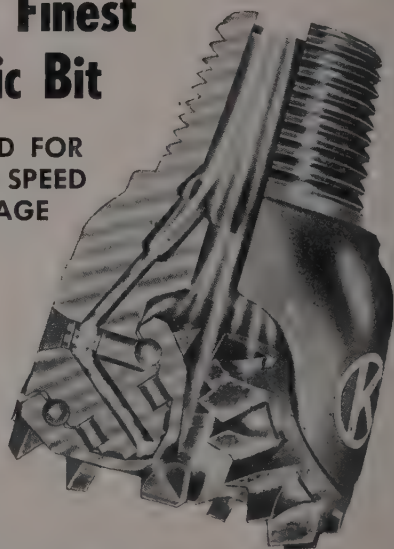


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# IT HAPPENED TO PANAIYOIKYASI \*

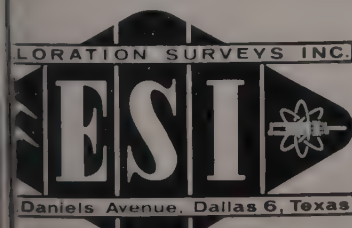


ITY OF THE HOPI WATER CLAN  
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his power was nullified and could never  
sed by people ● The magnificent full  
tial of the many exploration tools used

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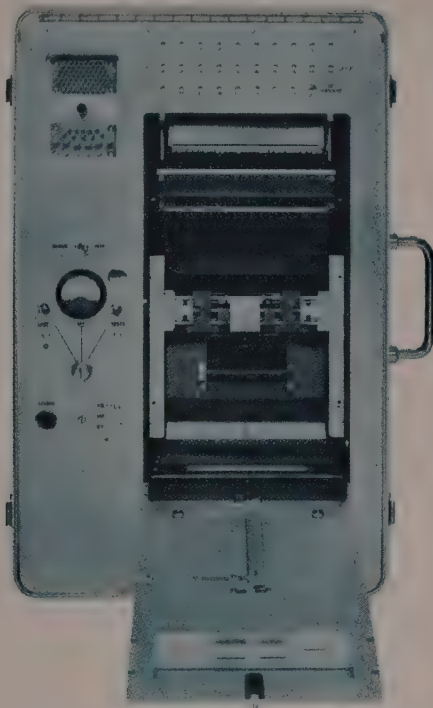
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(The members of the G.S.T. were asked to fill out and return a form listing the honors received, offices held, and/or papers presented during the period covered by these *Proceedings*, 1961-1964. The following list is based upon the replies—Editors.)

- Alexander, Warren A., Treasurer, G.S.T., 1961-62; S.E.G. Silver Certificate, 1964.
- Bemrose, John, Secretary, G.S.T., 1963-64; Associate Editor, S.E.G., 1961-63; Chairman, Teller's Committee, S.E.G., 1963-64.
- Bike, Peter, Editor-Elect and Editor, G.S.T., 1961-63.
- Born, W. T., G.S.T., Certificate of Merit—Past President, 1963.
- Broding, R. A., Treasurer, G.S.T., 1963-64.
- Brooks, C. C., "Application of Seismograph Exploration in Ohio", presented before Ohio Geological Society, Columbus, Ohio.
- Bryan, A. B. G.S.T., Certificate of Merit—Past President, 1963.
- Buffum, C. E., S.E.G., Silver Certificate, 1964.
- Campbell, Francis F., S.E.G. Silver Certificate, 1962.
- Clark, R. C., S.E.G. Silver Certificate, 1964.
- Coffin, R. Clare, G.S.T. Certificate of Merit—Past President, 1963; S.E.G. Silver Certificate, 1962.
- Cooper, Jack R., S.E.G. Silver Certificate, 1962.
- Courtier, William H., S.E.G. Silver Certificate, 1962.
- Crawford, John M., S.E.G. Distinguished Lecturer, 1963, "Case History of an Exploration Method—Vibroseis", G.S.T. Certificate of Merit—Past President, 1963; S.E.G. Silver Certificate, 1962.
- Day, Charles E., S.E.G. Silver Certificate, 1964.
- Dyk, Karl, S.E.G. Silver Certificate, 1964.
- Erdahl, William M., G.S.T. Certificate of Merit—Past President, 1963.
- Ericson, Harry B., S.E.G. Silver Certificate, 1964.
- Faust, L. Y., G.S.T. Certificate of Merit—Past President, 1963; presented "S.E.G. and the Geophysical Industry", "Fargo Field—A Case History", "Applied Serendipity".
- Ferris, Craig, S.E.G., Secretary-Treasurer, 1963-64, Silver Certificate, 1964; President G.S.T., 1963-64; District Representative to S.E.G., 1961-63; presented "Gravity and Compaction Anticlines" before Annual Meeting of A.A.P.G., Toronto, May 1964.
- Finn, Robert S., Second Vice-President G.S.T., 1963-64.
- Gemmer, R. W., G.S.T. Certificate of Merit—Past President, 1963.
- Geyer, Robert L., S.E.G. Best Presentation Award for "SH Waves from Explosive Sources" (co-author with S. T. Martner), given before Research Session, Annual Meeting, Calgary, September 1962; Editor-Elect G.S.T., 1963-64.
- Green, Ted S., G.S.T. Certificate of Merit—Past President, 1963; District Representative to S.E.G. 1963-64.
- Hammer, Signmund, S.E.G., Honorary Life Membership 1962; "Rock Densities and Vertical Gradient of Gravity in the Earth's Crust", 1962; "Deep Gravity Interpretation by Stripping", 1962.
- Hargis, A. V., S.E.G. Silver Certificate, 1964.
- Harlton, Bruce H., S.E.G. Silver Certificate, 1963.
- Hawkins, James E., President G.S.T., 1961-62; G.S.T. Certificate of Merit — Past President, 1963; District Representative to S.E.G., 1963-64; S.E.G. Silver Certificate, 1964.
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Martner, S. T., S.E.G. Best Presentation Award for "SH Waves from Explosive Sources" (co-author with R. L. Geyer) presented before S.E.G., Calgary, 1962; "Broomstick Distributed Charges", S.E.G., Denver, 1961.  
McCollum, E. V., S.E.G. Silver Certificate, 1962.  
McNally, P. M., District Representative to S.E.G., 1961-1963.  
Noble, Jack A., "Computer Applications in Geophysics", G.S.T., February 1963.  
Perry, Waynard B., First Vice-President G.S.T., 1963-64; S.E.G. Silver Certificate, 1964.  
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Rummerfield, Ben F., District Representative to S.E.G., 1961-63; "The Use of Computers in the Petroleum Industry" (co-author with Norman S. Morrissey), Symposium at Stanford Univ., June 1963; "How to Evaluate Exploration Prospects" (co-author with Norman S. Morrissey) Annual Meeting of A.A.P.G. at Houston, 1963, at Annual Meeting of S.E.G. at New Orleans, Oct. 1963 and at local meetings in U. S. and Canada.  
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Silverman, Daniel, S.E.G. Silver Certificate, 1964; "MURAC—A Multiple Reflection Analog Computer" (C. H. Hadley and C. C. Lash co-authors), presented at Annual Meeting of S.E.G., Calgary, Sept. 1962; "SADAC—A High-Speed Electronic Digitizing System" (C. C. Hadley co-author), presented at Annual Meeting of S.E.G. New Orleans, Oct. 1963.  
Skelton, J. D., First Vice-President G.S.T., 1961-62.  
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## GEOLOGY OF OKLAHOMA – A SUMMARY

LOUISE JORDAN

*Oklahoma Geological Survey*

### INTRODUCTION

The following summary of the geology of Oklahoma has been written at the request of the Geophysical Society of Tulsa and is intended mainly as an aid in understanding the major geophysical anomalies shown on the accompanying magnetic and gravity maps of the State. Because much of the geology is too complex for simple treatment, however, the text has been abbreviated, it is mainly descriptive, and the geology of the Oklahoma Panhandle has been omitted.

The principal theme of the paper is regional geology. Accordingly, the discussions are concentrated on major stratigraphic and structural provinces, and these are elucidated by an outcrop map and sections, by a structure contour map on top of the basement rocks, and by pre-Pennsylvanian and pre-Woodford maps.

Most of the sedimentary rocks of Oklahoma are of Paleozoic age, locally 40,000 to as much as 60,000 feet thick. In the southern third of Oklahoma are the three principal fold belts of the State, all originating from orogeny and uplift in Pennsylvanian time. North of the fold belts are two deep basins, and north of these basins are the tectonically stable shelf areas of northern Oklahoma. Petroleum is found in all the provinces and is produced from 72 of the 77 Oklahoma counties. An intensive exploratory program of drilling for oil and gas during the past 50 years has provided most of the subsurface information, which is a critical part of the report.

For valuable assistance in preparing the manuscript the writer is indebted to William E. Ham of the Oklahoma Geological Survey, and to Peter Jacobsen, Jr., and Paul L. Lyons of the Geophysical Society of Tulsa.

### ROCKS OF OKLAHOMA

For convenience of discussion, rocks in Oklahoma are divided into ten main units. All these units crop out within some part of the State, but Pennsylvanian and Permian strata crop out over most of the State as shown on the generalized geologic map (Fig. 1). The youngest stratigraphic unit consists of Tertiary-Quaternary strata in the western part of the State and in the Panhandle. They occur as a thin blanket of sandstone, siltstone, and caliche and are not further discussed in this report. Tertiary-Quaternary deposits along stream valleys are not shown on the map. The principal units in descending order are (1) Mesozoic, (2) Permian, (3) Pennsylvanian, (4) Mississippian, (5) Devonian-Silurian, (6) Upper and Middle Ordovician, (7) Lower Or-

dovician and Upper Cambrian, (8) Middle and Lower Cambrian, and (9) Precambrian. The stratigraphic names referred to in this report are given in stratigraphic sequence in Figure 2.

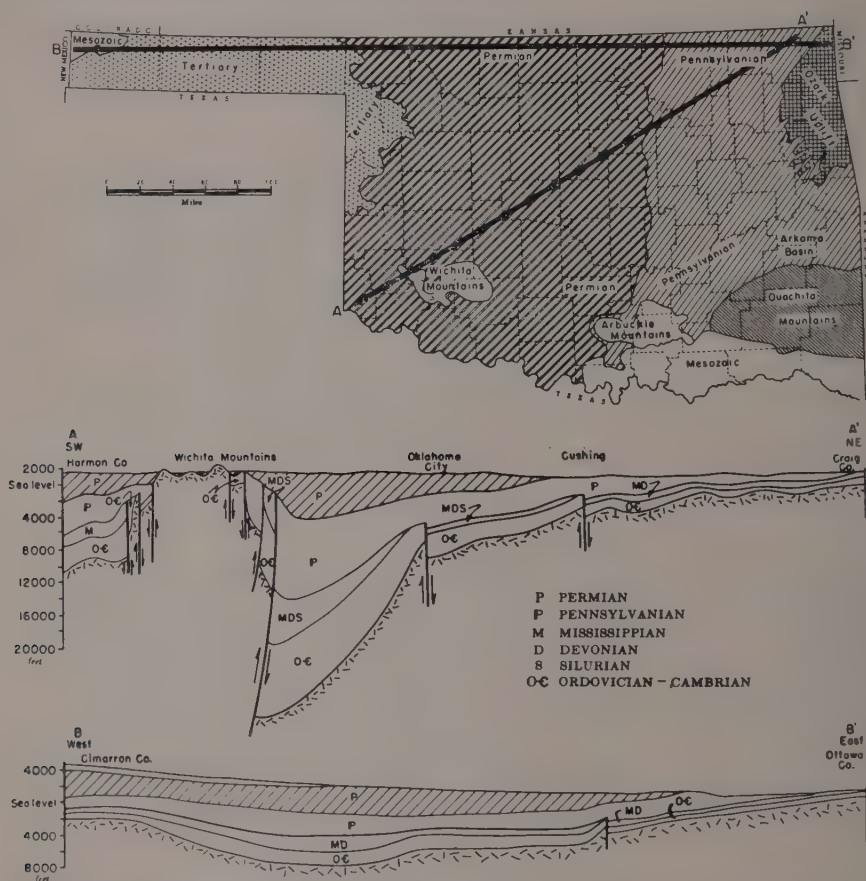


Figure 1. Generalized geologic map and sections of Oklahoma.

### MESOZOIC ROCKS

The Mesozoic is represented mainly by Cretaceous rocks. Strata of this age are present in the Cretaceous Gulf Coastal Plain of south-central and southeastern Oklahoma. The rocks are essentially limestones, clays, and sands, and the sequence unconformably overlies rocks ranging in age from Pennsylvanian to the Precambrian in the southern parts of the Marietta basin, Ardmore basin, Tishomingo-Belton segment and the Ouachita province (Figs. 1 and 3). This section containing rocks of Gulfian and Comanchean age

thickens from a featheredge along the northern extent to more than 3,500 feet in the southeastern corner of Oklahoma. A few Cretaceous outliers are present in northwestern Oklahoma and are significant only in that they indicate previous cover and erosion.

|                               |                                                           |                  |
|-------------------------------|-----------------------------------------------------------|------------------|
| Cretaceous                    | Gulf                                                      |                  |
|                               | Comanche                                                  |                  |
| Permian                       |                                                           |                  |
|                               | Virgil                                                    | Arbuckle orogeny |
|                               | Missouri                                                  |                  |
| Pennsylvanian                 | Des Moines                                                |                  |
|                               | Atoka                                                     |                  |
|                               | Morrow                                                    | Wichita orogeny  |
| ?                             | Springer                                                  |                  |
|                               | Chester, Goddard                                          |                  |
| Mississippian                 | Meramec, Jackfork, Stanley                                |                  |
|                               | Osage                                                     |                  |
|                               | Kinderhook                                                |                  |
| Devonian and Silurian         | Woodford, Chattanooga, Arkansas Novaculite                |                  |
|                               | Hunton, Missouri Mountain, Blaylock                       |                  |
| U. and M. Ordovician          | Sylvan, Polk Creek                                        |                  |
|                               | Fernvale-Viola, Bigfork Chert                             |                  |
|                               | Simpson, Womble                                           |                  |
| L. Ordovician and U. Cambrian | Arbuckle                                                  |                  |
|                               | Timbered Hills (Reagan Sandstone at base)                 |                  |
| M. and L. Cambrian            | Rhyolite, granite, gabbro, spilitic basalt, metasediments |                  |
| Precambrian                   | Granite, rhyolite                                         |                  |

Figure 2. Stratigraphic succession and equivalent terms used in this report. Regional major unconformities shown by wavy lines. Vertical bars show range of hiatus associated with Wichita orogeny and pre-Woodford unconformity.

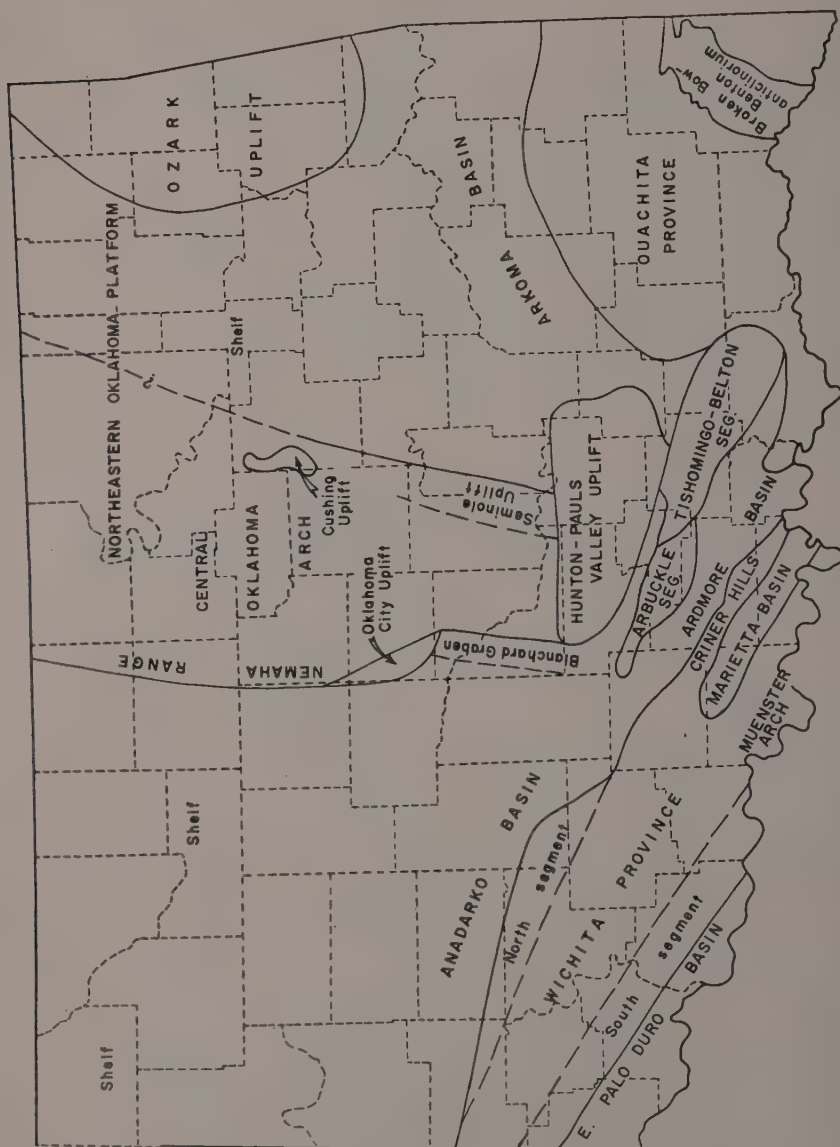


Figure 3. Major structural features and provinces of Oklahoma (exclusive of Panhandle).

## PERMIAN ROCKS

Permian rocks are present in the western two-thirds of Oklahoma (Fig. 1). North of the Wichita province the sequence consists of basal marine carbonates and shale overlain by four evaporite sequences separated by red shale, siltstone, or sandstone. Only the uppermost sequences, Blaine and Cloud Chief, crop out. The lower three evaporite units consist of halite, anhydrite, dolomite, and shale. Halite clearly predominates in part of the section and occurs in as much as 2,000 feet of strata, some of it almost pure rock salt 1,000 feet thick. Maximum salt thickness for one stratigraphic unit does not coincide structurally or geographically with maximum thicknesses of other evaporite units. In the southeastern part of the Anadarko basin and in the Ardmore basin, evaporite strata are absent and the rocks are mainly sandstone, shale, and conglomerate.

Thickness of Permian rocks in western Oklahoma increases from 3,000 feet at the north to more than 6,500 feet in the deeper part of the Anadarko basin. In parts of the Wichita Mountain province these rocks rest directly upon basement. Southward in the eastern Palo Duro basin, the rocks are mainly red shale with some evaporites, carbonates, and granite wash.

## PENNSYLVANIAN ROCKS

The generalized geologic map (Fig. 1) shows the area of outcropping Pennsylvanian rocks in the eastern part of Oklahoma where the homoclinal sequence has been beveled by erosion. Pennsylvanian strata are divided into five series (descending), Virgil, Missouri, Des Moines, Atoka, and Morrow. Some geologists also place Springer in the Pennsylvanian. The rocks are primarily shale, but contain beds of sandstone, limestone, coal, and conglomerate. Along the northern and southern flanks of the Wichita uplift, coarse clastic sediments (granite wash) grade basinward into sandstone, siltstone, and shale. Coarse clastics are present near major uplifts such as the Arbuckle segment and the Criner uplift.

Early Pennsylvanian rocks, Morrow and Atoka, are absent over the Central Oklahoma arch (Fig. 3), over anticlines in the Ardmore basin, and in the shelf areas of the Arkoma and Anadarko basins delineated for the most part by the northern edge of Morrow rocks as shown by the dotted lines on Figure 4. In western Oklahoma, thickness of Pennsylvania strata ranges from 2,000 feet near the Kansas boundary southward to more than 16,000 feet in the deeper part of the Anadarko basin. Here approximately 9,000 feet of the section is assigned to Morrow and Atoka, which are absent in the north. In the eastern Palo Duro basin in southwest Oklahoma, the sequence attains a thickness of about 4,000 feet and reportedly contains all units of the Pennsylvanian.

In the Ardmore basin, thicknesses of Pennsylvanian strata (Virgil to Morrow inclusive) range up to 15,000 feet, but here 5,000 to 8,000 feet of the section is assigned to the Des Moines. In the southeastern deeper part of the Marietta basin, the base of the Pennsylvanian is reached at a depth below 14,000 feet. Cretaceous rocks less than 1,000 feet thick overlie Late

Pennsylvanian strata. Atoka, and possibly Morrow, rocks are confined to the deeper part of the basin.

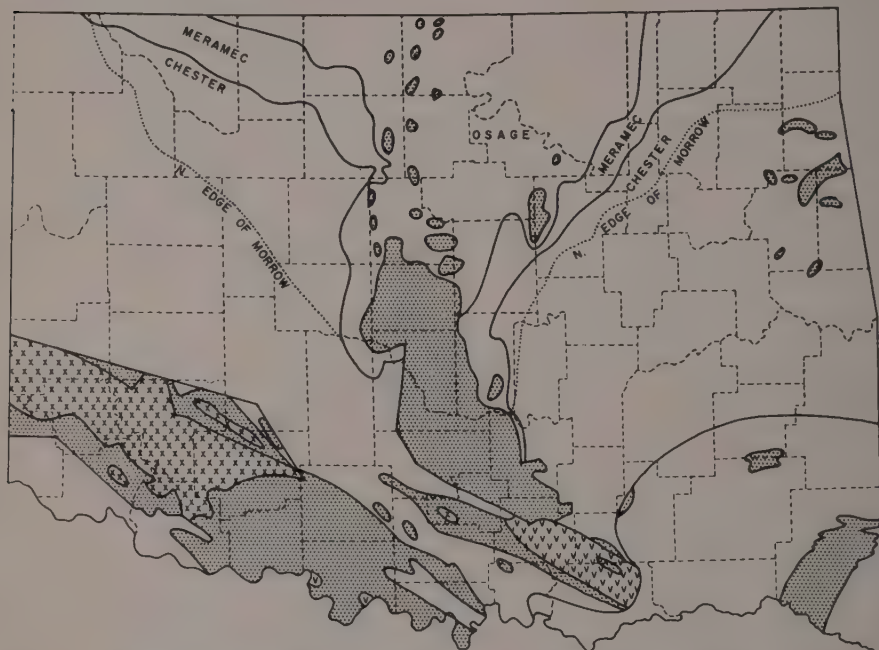


Figure 4. Generalized geologic map of pre-Pennsylvanian rocks in Oklahoma (exclusive of Panhandle) showing surface and subsurface distribution. Blank areas indicate Mississippian strata. In north-central Oklahoma, Mississippian rocks are subdivided into Chester, Meramec and Osage. Stippled areas indicate Devonian, Silurian, Ordovician, and Upper Cambrian strata. Middle and Lower Cambrian igneous rocks are indicated by X's and Precambrian igneous rocks are show by V's.

In the Arkoma basin, the strata are mainly shale with some sandstone. They attain a thickness of at least 15,000 feet north of the Choctaw fault of the Ouachita province. At the surface, Des Moines rocks, locally absent, range from 1,000 to 3,500 feet in thickness. Most of the section is assigned to the Atoka, the Morrow unit being less than 1,000 feet thick.

#### MISSISSIPPIAN ROCKS

Figure 4, a generalized geologic map of pre-Pennsylvanian rocks, shows the area where Mississippian rocks are present at the surface and in the subsurface. The greatest thickness of Mississippian strata is in the Ouachita province where alternating strata of sandstone and shale, primarily of the Stanley and Jackfork groups, (Meramec) attain a thickness of more than 20,000 feet. Westward in the Ardmore basin the Late Mississippian Goddard and Springer, approximately 4,500 feet thick, are mainly shale and sandstone.

They are underlain by a sequence of Mississippian shale and silty carbonate 500 to 700 feet thick. Chiefly of Meramec age, they contain about 100 feet of

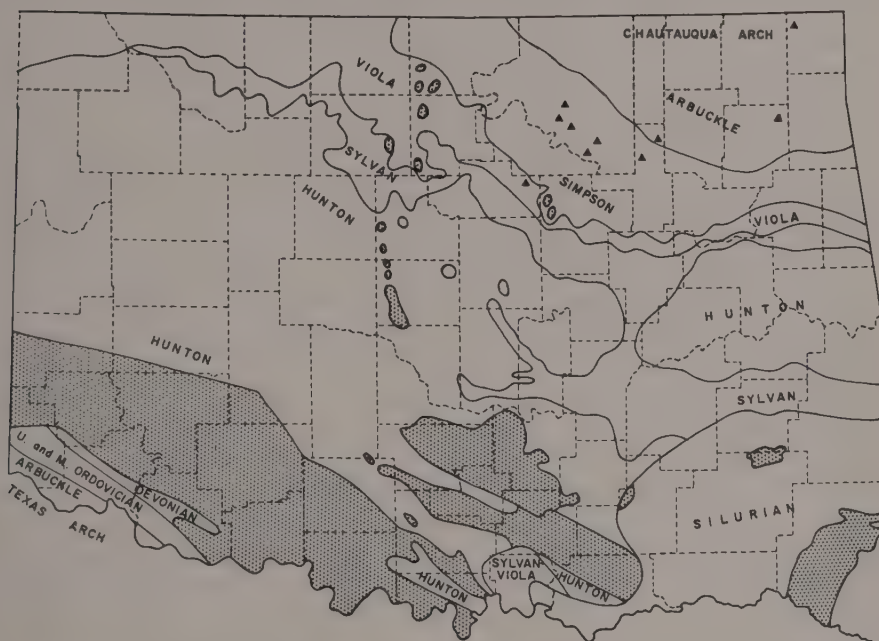


Figure 5. Map showing distribution of rock units at post-Hunton unconformity and sub-Woodford or sub-Mississippian surface (exclusive of Panhandle). Stippled areas are those from which Woodford and Mississippian strata have been removed by Pennsylvanian uplift and erosion. Triangles represent sharp local topographic highs on basement surface.

strata which may be assignable to the Osage and Kinderhook. In the Marietta basin the Goddard and Springer are absent.

In western Oklahoma both north and south of the Wichita uplift, the Mississippian strata are primarily carbonate rocks 1,500 to more than 3,500 feet thick. Within the Anadarko syncline and on its flanks, equivalent strata are overlain by Springer shales and sandstones. In the Elk City field, the Springer is 1,450 feet thick, but the base of the Mississippian has not been reached at a total depth of 24,003 feet. Southeastward toward the Ardmore basin (Cement field), a well drilled 6,861 feet of steeply dipping Mississippian beds without reaching the base of the Mississippian.

In northern Oklahoma where the Chester and/or Meramec units (Fig. 4) have been removed by pre-Pennsylvanian erosion, the remaining Meramec or Osage rocks are principally cherty carbonates ranging in thickness from 200 to 600 feet.

In northeastern Oklahoma, the Mississippian is represented by carbonates about 400 feet thick in the lower part of the system, whereas in the Arkoma basin to the south Upper Mississippian shales predominate. North of the Choctaw fault, at the south edge of the Arkoma basin, the strata are 1,300 feet thick.

#### DEVONIAN-SILURIAN ROCKS

Except for the area of the Ouachita province, the Devonian-Silurian sequence consists of carbonate rocks of the Hunton group, together with the unconformably overlying Woodford Formation or Chattanooga shale (locally including a basal sandstone called Misener). Figure 5 shows the formations which underlie the Woodford or equivalent formations, or underlie Mississippian rocks where the Woodford is absent. The Hunton has been removed from the area of the Chautauqua arch and from much of northeastern and northern Oklahoma; farther south, on the east-trending Guthrie-Holdenville arch (Tarr, 1955), the Woodford rests upon Sylvan. Locally in the Ardmore basin, the Woodford rests upon Sylvan and Viola. The thickest recorded normal section (800 feet) is in a well in the Anadarko basin area of northeastern Caddo County. Southwest of this well, in central Caddo County, approximately 700 feet of the Hunton was encountered. Within the complex folded and faulted area of the North Wichita segment, much greater apparent thicknesses have been drilled.

In the Ouachita province a section of sandstone and shale respectively named the Blaylock and Missouri Mountain (Silurian), ranging in thickness from 800 to 1,000 feet, is overlain by the Arkansas novaculite. The novaculite is considered for the most part to be equivalent to the Woodford formation.

The Woodford is thickest in southern Oklahoma but is absent at places in the normal sequence in northeastern Oklahoma (parts of Osage, Rogers, and Wagoner Counties), in extreme northwestern Oklahoma (Harper County), and in the eastern Palo Duro basin. It is normally less than 50 feet thick in northern Oklahoma and is 300 to 500 feet thick in the Arbuckle Mountains and the Wichita province.

#### UPPER AND MIDDLE ORDOVICIAN ROCKS

Upper and Middle Ordovician rocks consist of the Simpson group and overlying Viola-Fernvale limestones and Sylvan shale.

The Simpson group is divided into six formations which consists of sandstone, limestone, and shale. Well-known oil- and gas-productive sandstones are in the Bromide, Tulip Creek, McLish, and Oil Creek formations (descending order). Informal names, such as Marshall zone and Wilcox sand, are applied to productive sandstones of Simpson age in northern Oklahoma. The areal distribution of each of these units is not everywhere the same in the State. For instance, the Tulip Creek formation is limited generally to the basinal area or southern part of the State, whereas the Bromide,

McLish, and Oil Creek formations are more widely distributed. The group thins northward and southwestward, away from the area of greatest subsidence in the Anadarko-Ardmore depositional basin. Those units which extend toward the Chautauqua arch have been truncated by pre-Woodford erosion in northeastern Oklahoma as shown in Figure 5. The group is thickest in southern Oklahoma and decreases to less than 300 feet in northern Oklahoma where it is overlain by Viola-Fernvale limestones. Thickness at the outcrop in the Arbuckle segment is about 2,300 feet and may be as much as 2,500 feet in this vicinity. In the Ouachita province most of the Womble shale section is equivalent to the Simpson group and is about 600 feet thick.

The Viola-Fernvale limestones, which overlie the Simpson group in all areas except where eroded by pre-Woodford or later erosion, attain a maximum thickness of not more than 1,000 feet in the Ardmore basin of southern Oklahoma. Just north of the Ouachita province the thickest section recorded is less than 200 feet. In the northwestern shelf area, where overlain by Sylvan shale, the carbonate section is normally not more than 200 feet thick, and locally may be less than 100 feet thick. In the Ouachita province, equivalent strata, the Bigfork chert, are from 600 to 700 feet thick and consist of chert and limestone or cherty limestone with interbedded shale.

The Sylvan shale, highest named unit in the Ordovician in Oklahoma and equivalent to the Polk Creek shale in the Ouachita province, attains a maximum thickness of probably less than 350 feet. The areas of greater thickness are probably in the Ardmore basin and in the Arbuckle segment. The unit is absent in northeastern Oklahoma and near the Kansas border in northwestern Oklahoma because of pre-Woodford erosion. The shale unit is not recognized in most of Harper County, and may be absent because of nondeposition or pre-Hunton erosion. It thins to extinction westward from Frederick in the eastern Palo Duro basin, perhaps because of pre-Devonian erosion.

#### LOWER ORDOVICIAN AND UPPER CAMBRIAN ROCKS

Rocks of this age in Oklahoma consist of the Timbered Hills group and part of the overlying Arbuckle group. Other names are applied in northwestern Oklahoma, but the general section is equivalent and in this report is referred to Arbuckle dolomite. Except for the basal Reagan sandstone, most of the rocks in this sequence are carbonates. They are widely distributed in all parts of Oklahoma except in the Ouachita Mountains, where the known equivalent Ordovician beds are black shale and sandstone. Maximum thickness of the strata is in the Anadarko-Ardmore depositional basin of southern Oklahoma, ranging in this area between 6,000 and 8,000 feet. In south-central (Pauls Valley-Hunton uplift) and central Oklahoma, they are 3,000 to 4,000 feet thick, whereas in northern Oklahoma the section is 1,000 to 1,500 feet thick. South of the Wichita uplift in the Palo Duro basin, the same strata generally are 1,500 to 3,000 feet thick. The basement surface in northeastern Oklahoma is characterized by many small peaks (Fig. 6) of igneous rock which are referred to collectively as the "Tulsa Mountains." The hills, many with relief

of 1,000 feet or more, were mostly buried by Arbuckle dolomite, but some were not completely covered until Mississippian time. Erosion subsequent to Wood-

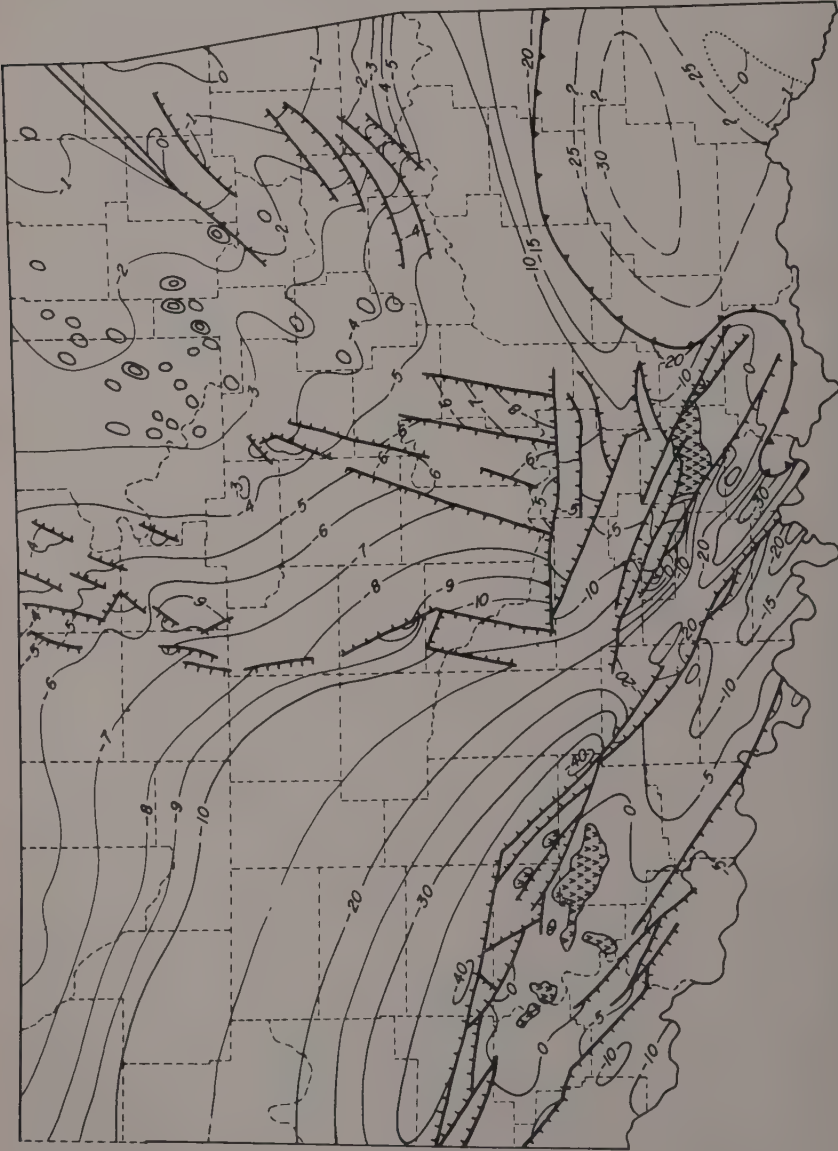


Figure 6. Generalized contour map of basement rocks in Oklahoma (exclusive of Panhandle). Patterned areas are basement-rock outcrops. Contour interval: 1,000 and 5,000 feet.

ford or Mississippian deposition may have removed some of the Arbuckle section. Some of the peaks, indicated by triangles on Figure 5, protrude a few feet to more than a hundred feet above the Arbuckle surface. Thickness of the Arbuckle near these peaks is directly related to the relief of the hills, and the lower part of the Arbuckle is found only in the valleys between the hills.

#### MIDDLE AND LOWER CAMBRIAN ROCKS

Rhyolite, granite, gabbro, basalt-spilite, and metasediments make up the basement rocks of the Wichita province. They have an isotopic age range of 500 to 550 million years. Igneous rocks of this age also crop out in the Arbuckle segment (Fig. 4), and underlie the Anadarko, Marietta, and Ardmore basins.

Metamorphosed sediments of this age and perhaps younger are referred to as basement in the core area of the Ouachita province in southeastern Oklahoma (Fig. 6).

#### PRECAMBRIAN ROCKS

Ages of Precambrian igneous rocks, mainly granite and rhyolite, have been isotopically dated from 1,050 to 1,350 million years, in northeastern Oklahoma and in the areas of the Central Oklahoma arch, the Hunton-Pauls Valley uplift, the Tishomingo-Belton segment of the Arbuckle Mountains, and the Muenster arch. The granites are distinct petrographically, petrologically, and chemically from the Wichita granites of Cambrian age.

#### MAJOR UNCONFORMITIES AND STRUCTURE

Surfaces of erosion subsequent to regional tectonic disturbance are keys to an understanding of the distribution of rocks and their thicknesses at interfaces of major unconformities.

The two major orogenies involving Paleozoic strata of Oklahoma are those that are easily recognized in the tectonic provinces in the southern one-third of the State. The orogenies are mostly confined to Pennsylvanian time, and occurred during strong pulses that extended from early Middle Pennsylvanian time up to the close of the Pennsylvanian period. Different areas were affected to different degrees by these deforming stresses.

The earlier pulse, commonly called the Wichita orogeny, is characterized by strong folding and uplift of pre-Atoka strata. Many of the upfolded structures that now contain vast amounts of oil were first formed during this period of unrest. The arkosic sediments which surround and largely conceal the Wichita Mountains indicate that highlands of igneous rock survived for a longer time here than in the Arbuckle Mountains area.

The latest orogenic pulse is called the Arbuckle orogeny. The Arbuckle segment was strongly uplifted in post-Missouri (Hoxbar) and pre-Vanoss time, culminating in great uplift in the Arbuckle segment and intense compression of the Ardmore basin. Close folding accompanied by major faulting occurred at this time, and structures formed previously by the Wichita orogeny were modified.

The time of folding of the great Ouachita fold belt cannot be precisely determined, but it is believed by some to have taken place in Oklahoma near the end of Atoka time. The Ouachita orogeny intensely compressed the Ouachita geosyncline, raising the Ouachita Mountains into high relief so that great wedges of chert conglomerates, sands, and deltaic sediments extend northwestward into the Ardmore basin. Later pulses possibly extended upward into Permian time.

#### BASEMENT SURFACE AND PRE-UPPER CAMBRIAN UNCONFORMITIES

The present relief of the basement surface of the State is speculatively presented in Figure 6. Control is limited to some 600 wells in northeastern Oklahoma and in the southern part of the State west of the Ouachita province. No wells have penetrated basement in the Anadarko basin and shelf area, in most of central Oklahoma, in the deeper part of the Arkoma basin, or in the Ouachita province. Basement rocks crop out in the Wichita and Arbuckle Mountains and on the Ozark uplift. If the metasedimentary rocks of Early Paleozoic age are accepted as basement in the Ouachita province, as proposed by some, the basement crops out in the Broken Bow-Benton anticlinorium; Figure 6 is so contoured. Late Cambrian and Ordovician sediments accumulated upon the basement surface. The unconformity between Precambrian rocks and sedimentary rocks is a major one, as for example in the "Tulsa Mountains", and in other parts of northeastern Oklahoma, and in the Tishomingo-Belton segment of the Arbuckles. However, the Reagan sandstone, the lowermost formation of Late Cambrian age, is structurally conformable to the layered igneous basement rocks of Early and Middle Cambrian age, and the unconformity is relatively minor in the Wichita province, the Anadarko, Marietta, and Ardmore basins, and the Arbuckle segment.

Late Cambrian-Devonian deposition was interrupted many times, and on three occasions major unconformities were developed when older rocks were regionally tilted at low angles and beveled. These unconformities are those developed before Simpson deposition, at the end of Sylvan deposition, and between the time of accumulation of the Silurian and Devonian parts of the Hunton group.

#### POST-HUNTON UNCONFORMITY AND SUB-WOODFORD (CHATTANOOGA) SURFACE

Figure 5 is a generalized map showing distribution of rocks below the Woodford (Chattanooga) shale, or where it is absent, below Mississippian rocks. Areas of major post-Mississippian erosion are shown by stipple pattern, and it is assumed that most of these areas were once covered by upper Cambrian-Devonian rocks. Omitting the Ouachita province, parts of three major structural provinces are shown: (1) northwestward-trending Southern Oklahoma geosyncline (an extension of the Colorado sag of Eardley), (2) flank of the Ellis-Chautauqua-Ozark dome to the north, and (3) flank of Texas arch to the southwest. Several areas of upwarps are shown where Hunton is

absent and Woodford rests upon Sylvan or Viola. Mississippian, Pennsylvanian, and Permian tectonic disturbances mask pre-Woodford structures and make interpretation difficult. However, thickness maps of individual units of the pre-Woodford sedimentary sequence reveal many other areas where faulting, uplift, and erosion occurred previous to Woodford deposition. Many prominent anticlines in southern Oklahoma, such as at Apache and Carter-Knox, and along the axes of the Caddo, Overbrook-Enville, and Mannsville-Madill-Aylesworth anticlines, give evidence of pre-Woodford movements. Evidence is also present at the surface in the Arbuckle Mountains area.

#### SUB-PENNSYLVANIAN SURFACE AND POST-MISSISSIPPIAN UNCONFORMITY

Figure 4 is a simplified map showing the present distribution of rocks older than Pennsylvanian in the surface and subsurface. Tectonic activity and erosion during Pennsylvanian and Permian time and in later periods have affected the distribution of pre-Pennsylvanian rocks in most of southern Oklahoma and on the Ozark uplift. The Central Oklahoma arch and most of northern Oklahoma, the Pauls Valley-Hunton uplift, the northwestward-trending faulted anticlines lying en echelon between the Arbuckle and Wichita Mountains, the Muenster arch, and the Criner Hills uplift were positive elements developed prior to Atoka deposition and were finally buried by upper Des Moines strata of the Pennsylvanian. The Central Oklahoma arch is bounded on the west and east by northward-trending zones of normal faults. Eastward-trending faults are also present. Complexly faulted uplifts appear to be more abundant along the western boundary, called the Nemaha Range. This southward-trending arch was a barrier between the Anadarko and Arkoma shelves and part of the basin areas at least during Atokan time, and probably during Morrowan time. Atoka and Des Moines strata overlap the flanks of the arch and some parts were not covered until late Desmoinesian time.

In parts of southern Oklahoma, such as in the Marietta basin, the unconformity is considered to be pre-Atokan in age. Many geologists state that, in the Anadarko basin, where Springer strata are present, sedimentation was continuous from Mississippian into Pennsylvanian time, but in the Ardmore basin, the Springer beds over many structures are unconformable with the overlying Pennsylvanian formations. Study of oil-productive anticlines, such as Carter-Knox and Cement in the southeastern Anadarko basin area, where many thousands of feet of Pennsylvanian-Springer-Goddard rocks are present, indicates that thrust faults and normal faults are confined to these rocks. Pre-Chester formations may have been folded at the time of faulting, or the first evident structural movement may have been post-Hunton and pre-Woodford.

In the Wichita province, the central core area of basement rock is partly covered by a thin veneer of dominantly Permian rocks and is flanked to the north and south by complex horst-and-graben blocks formed during uplift of the structural element in Pennsylvanian time. The prominent west-northwest fault pattern is transected by northeastward striking cross faults in the entire province. This basin area of Upper Cambrian through Chester

deposition was uplifted sufficiently so that Early Paleozoic igneous and sedimentary rocks contributed significantly to the Des Moines-Missouri-Virgil and Early Permian sequence of the surrounding area.

The structural pattern of the Ouachita province consists primarily of long linear folds, many of which were ruptured to produce thrust faults directed toward the north and northwest. Strike-slip movement of the mass is postulated along transverse faults bordering the Arbuckle buttress, and this type of movement extended into the Arbuckle Mountains area. The Broken Bow-Benton anticlinorium forms the central part of the range where pre-Stanley rocks (Devonian and older) with incipient to low-grade metamorphism crop out in the southeasternmost county of the State. Major tectonic deformation and uplift occurred during Middle Pennsylvanian time, and the core of the Ouachitas was exposed, probably in Early Permian time, before deposition of Cretaceous strata.

The Ozark uplift, a southwestward extension of the Ozark dome, was a broad, stable, positive element during much of geologic time. Northeastward-trending folds and normal faults are roughly parallel to the axis of the feature. These are mapped southwestward into the subsurface. On the southern part of the uplift, the trends of the faults are more easterly and roughly parallel to the folds and faults of the Arkoma basin, indicating a genetic relationship to Ouachita deformation.

Principal deformation of the Arbuckle and Tishomingo-Belton segments, occurring in Late Pennsylvanian time, caused the formation of overturned folds, normal and thrust faulting in these segments as well as in the Ardmore basin, Criner Hills, and Marietta basin. Strike-slip movement is postulated along the northwestward-trending, through-going faults, which are both normal and reverse faults.

## PRESENT LAND SURFACE

Regional movements, with the resultant down warping and development of extensive seas to the west of Oklahoma during Late Permian through Jurassic time and the partial submergence of Oklahoma during Cretaceous time, introduced a general westward and southwestward tilting of rock strata in much of the area. This is revealed at the surface by the northward-trending bands of Pennsylvanian outcrop in the areas where the strata have not been affected by the major orogenies of southern Oklahoma or by the Ozark uplift. The outcrop bands of Early Permian rocks indicate the position of the Anadarko basin, but are interrupted in the southern part of the State by the Wichita Mountains.

The Cretaceous and Early Tertiary uplifts that produced the Rocky Mountains also imparted a slight eastward tilt to all the rocks in Oklahoma and gave the present eastward slope of the land surface, with elevations ranging from 5,000 feet at the northwestern tip of the Oklahoma Panhandle to 300 feet along the Red River in the southeast corner of the State.

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## VERTICAL-INTENSITY MAGNETIC MAP OF OKLAHOMA

V. L. JONES

Consulting Geophysicist

### INTRODUCTION

The first regional magnetic map of Oklahoma was prepared by L. Spragen and published in the *Oil and Gas Journal* of November 1, 1928. As a matter of historical interest it is reproduced here by permission from the publisher (Fig. 1).

The data for this vertical-intensity magnetic map of Oklahoma were obtained by computing the vertical component of the earth's magnetic field from data published by the United States Coast and Geodetic Survey. These data were usually taken at county seats and in most cases they were relatively old, unrevised and of questionable accuracy in comparison to modern magnetic measurements. The three elements of the magnetic field usually measured by the USCGS in the early days were: declination, inclination and horizontal component; the vertical component was computed from this information.

The magnetic map presented here (See Plate I, in pocket.) is, of course, based on much more control and on more accurate measurements. Yet the early map does call attention to some of the larger magnetic anomalies in the State, since confirmed and more completely delineated by detailed surveys.

The present compilation was begun in the summer of 1963. The objective of the project was to obtain from the oil industry and other sources enough data, preferably of the vertical component, to prepare an authoritative map for all of Oklahoma. At first it seemed like a hopeless undertaking, for it was not known whether the entire State had been covered by magnetic surveys, nor how much of the information could be made available. As time passed, however, it became evident that data for the entire State did exist in the files of several oil companies, various geophysical contractors and the U.S. Geological Survey.

The project got off to an encouraging start when two major oil companies anonymously made their magnetic information available. These data covered nearly two-thirds of the State. To these organizations the Society is deeply indebted for launching the project. We are also greatly indebted to the Oklahoma Geological Survey, which undertook the final drafting and printing of the magnetic and gravity maps accompanying this issue of the *Proceedings*. Others who participated in procuring data for the magnetic map by either supplying additional material, making known its source, or proffering their assistance in obtaining it were: USGS; The Pure Oil Company; Phillips Petroleum Company; Exploration Surveys, Inc.; Seismograph Service Corporation; and the U.S. Naval Oceanographic Office. To these organizations G.S.T. is grateful.

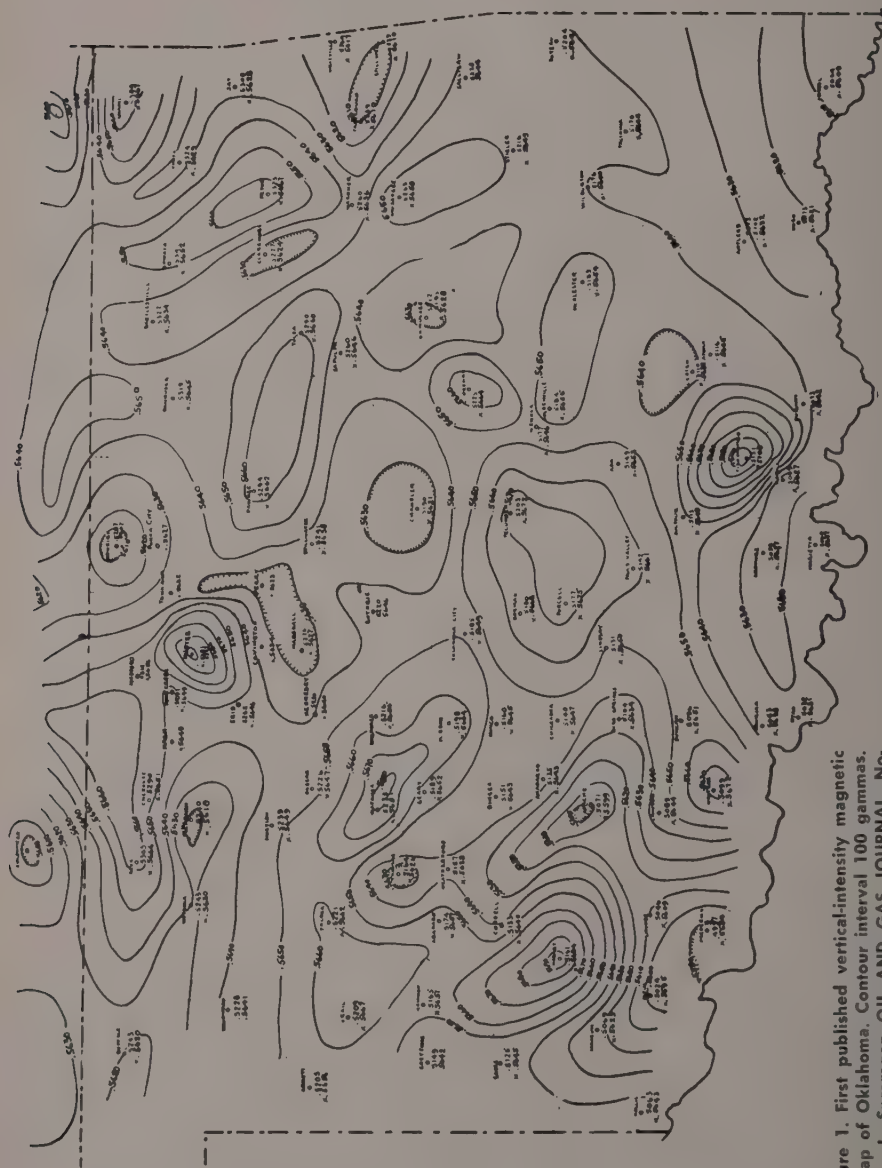


Figure 1. First published vertical-intensity magnetic map of Oklahoma. Contour interval 100 gammas. After L. Spragen Oil and Gas Journal, November 1, 1928. Published by permission.

After all the diverse data had been assembled and computed to an arbitrary datum, they were contoured on an interval of 100 gammas. At this point it was recognized that the sparse control in Osage County did not permit reliable contouring there. To remedy this situation the writer with the assistance of the Editor, Peter Jacobsen, Jr., ran an east-west profile across the County on January 4, 1964, using a modern torsion-type magnetometer which was made available by Seismograph Service Corporation. Thirty-one stations were obtained.

The arbitrary datum (zero contour on the map) was chosen as a rough median between the highest and lowest magnetic intensities found in the State of Oklahoma.

### SOME FUNDAMENTAL MAGNETIC CONCEPTS AND PRINCIPLES

Magnetic prospecting for oil and other minerals is the oldest method of geophysical exploration. The mathematical treatment of the principles and fundamental concepts of magnetics as applied in prospecting is the same as that in gravity work. Both are potential methods; i.e., potential theory is the mathematical tool used in analyzing their field behavior patterns under various parameter combinations and boundary value conditions. The analysis and interpretation of anomalous conditions in the magnetic field at and above the earth's surface is much more complicated than that of the gravity field, due to the fact that polarization is present in the source rocks of the former and is absent in the latter.

The somewhat circular pattern of the magnetic lines of force associated with a bar magnet is a manifestation of polarization. Since the direction of the magnetic field follows these lines of force, one may recognize immediately that the direction of the field at some point distant from the source is not necessarily along a straight line joining the point and the source, as is the case in a gravity field. Polarization is a characteristic of all magnetized bodies. It is a vector quantity, magnetic moment per unit volume, often referred to simply as the intensity of magnetization.

Two types of magnetization can be present, induced and remanent or permanent magnetization, and this further complicates the polarization. In the former the direction of polarization is the same as that of the earth's field, whereas in the latter the direction may be quite different from that of the inducing field. The direction of polarization in a rock source which exhibits both induced and remanent intensities is the direction of their vector sum.

Magnetic materials, including rocks and minerals, may be classified as ferromagnetic, paramagnetic and diamagnetic. A ferromagnetic or paramagnetic specimen free to rotate tends to align its elongate axis in the direction of the inducing field; a diamagnetic specimen aligns itself perpendicular to the inducing field. In the former the magnetic susceptibility is positive and in the latter it is negative. Most rocks and minerals dealt with in magnetic exploration are paramagnetic. Examples of diamagnetic materials are: bismuth, anhydrite and rock salt.

The intensity of magnetization of a rock source which has been polarized by induction in the earth's field is equal to its susceptibility times the earth's

field strength where the source rock is located, at or beneath the earth's surface.

A physical picture of the vector, magnetic moment per unit volume, may be had by using the concept of positive and negative (north and south) magnetic poles. The positive poles are distributed evenly on one face of a unit cubical volume and the negative poles at corresponding positions on the opposite face of the unit volume. The number of poles on either face (poles per unit area) is equal to the magnitude of the vector and the direction of alignment or pairing of the positive and negative poles on the opposite faces is the direction of the vector.

The earth itself exhibits a relatively weak magnetic field whose distribution and form is very nearly that which would result from a uniformly magnetized sphere; this is known as the earth's normal field. Its source, or sources, are still a matter of study and discussion among magneticians and theoreticians. Local and regional departures of the field from its normal, result from, among other causes, the heterogeneous distribution of rocks of differing magnetic susceptibilities in the earth's crust. The fields of these induced polarizations produce disturbances or anomalies in the normal field. Magnetic prospecting is primarily concerned with the detection and delineation of these anomalies at or above the earth's surface and with a precise measurement of their amplitudes and other characteristics. From such data inferences may be drawn regarding the size, shape and depth of burial of the subsurface rocks whose magnetic polarizations produce the anomalies.

The unit of magnetic field strength used in geophysics, the gamma, is one one-hundred-thousandth part of the cgs unit, the oersted.

If the distance between the positive and negative poles of a magnetized rock formation is small compared to its depth of burial, the field strength at and above the earth's surface resulting from the remanent and induced polarizations varies inversely as the cube of the distance. In the case of a vertically polarized dike or other elongate vertical formation where the lower set of poles may be considered to be at an infinite distance, the field strength varies inversely as the square of the distance, as in the case of the gravity field. In the former, the changes in the normal earth's field are often referred to as resulting from a magnetic dipole or dipoles. Other factors being equal, it is thus more difficult to detect a lithologic feature of small vertical extent than one of great vertical extent.

The susceptibilities of most sedimentary rocks are so small that their magnetic effects in the earth's field are not ordinarily discernible in magnetic prospecting. On the other hand, the susceptibilities of the igneous basement rocks, due in the main to their magnetite content, can be very much greater and the anomalies resulting from their polarization are, generally speaking, readily detectable, even when the source rocks are buried at relatively great depths.

The magnetic susceptibilities of igneous rocks themselves vary widely. The magnitude and configuration of a mapped anomaly depends not only on the size, geometry, and depth of burial of the magnetically polarized subsur-

face mass, but also on the difference between its susceptibility and the susceptibility of the adjacent rocks. It is this lateral variation in the susceptibility, usually called the susceptibility contrast which, together with the above-mentioned parameters, determine the magnitude, size and shape of the magnetic anomaly.

It is known from laboratory and other measurements that the magnetic properties of rocks and other magnetic materials decrease with increasing temperatures and that, at and above a critical temperature known as the Curie point ( $525^{\circ}$  C for magnetite), all ferromagnetic properties vanish. It would thus appear that there can be no ferromagnetic polarizations in the earth's crust or mantle at depths greater than about twenty kilometers. This point is questioned, however, by some magneticians, on the basis of extreme pressures and other unusual conditions at such great depths.

At the earth's magnetic equator the earth's total field is all in a horizontal direction, from south to north. At the magnetic pole in the southern hemisphere it is all vertically upward, whereas at the pole in the northern hemisphere it is all vertically downward. From the magnetic equator northward, the total field strength as well as its vertical component increase in magnitude and the horizontal component decreases. In magnetic prospecting corrections are made for these variations. They are known as the "normal corrections."

The earth's field has an irregular twenty-four-hour cyclic change known as the diurnal variation. It is attributed to the combined phases of the sun and moon. It is necessary that these diurnal changes be accurately measured in order to properly correct the observed field data. Other long-term changes in the normal field, known as secular variations, occur over periods up to many years.

In magnetic prospecting, then, there is no static theoretical model of the earth's field to which survey data may be referred, like the International Formula so widely used in gravity work.

In Oklahoma the absolute values of the normal magnetic field, its components and directions are as follows: The total field varies from approximately 54,500 gammas in the southern portion of the State to about 56,400 gammas in the northeast corner. At Tulsa it is 56,000 gammas. The angle of inclination varies from about  $64^{\circ}$  in the southern part to around  $67\frac{1}{2}^{\circ}$  in the northeast part. It is approximately  $67^{\circ}$  at Tulsa. The angle of declination varies from  $12^{\circ}$  east in the Panhandle to about  $8^{\circ}$  east in the eastern part of the State. It is  $9^{\circ}$  at Tulsa. The vertical component ranges from 49,000 gammas in the southern part to 52,000 gammas in the northeast; at Tulsa it is about 51,300. In extreme northeast Oklahoma the horizontal component is roughly 21,500 gammas and increases to around 23,800 in the southern areas. Its value at Tulsa is 22,200 gammas.

## INTERPRETATION OF MAGNETIC DATA

It is beyond the scope of this paper to review the more mathematical and technical methods of analysis and interpretation of magnetic data. There are two classic references on the subject. The earlier one, by L. L. Nettleton ("Gravity and Magnetic Calculations," *Geophysics*, v. 7, no. 3, 1942, p. 293-

310), deals only with analysis and interpretation techniques for vertical field data. The more recent one by Victor Vacquier, et. al., ("Interpretation of Aeromagnetic Maps," Memoir 47, Geological Society of America, 1951) outlines procedures for analyzing total field data.

Many authors have emphasized the point that geophysical interpretations of gravity and magnetic anomalies are nonunique, when arrived at only from the survey data. An infinite variety of mass distributions and depths of burial may yield the same surface anomaly, both in gravity and in magnetics. It is imperative, therefore, that other exploration data be used when available, to guide the choice of parameters involved in the calculations. Precise susceptibility and density contrasts are often difficult to determine; approximations are generally used. Depths of burial may in some cases be had from well logs. In all cases the values assigned to the various parameters must be geologically reasonable for the problem at hand.

The nature of the anomaly field associated with a "high" in a vertical-component survey can often be determined by also including a horizontal-component survey. If the anomaly field of the vertical "high" obeys the inverse cube function, i.e., the disturbing source has a relatively small finite vertical dimension, then the horizontal survey will in general reveal a "low" north of the vertical "high" and a "high" south of the vertical "low". It is often desirable to ascertain the nature of the vertical anomaly field when computing model studies to compare with observed anomalies.

It is the consensus of many that magnetics is simply a reconnaissance method. This was true in the early days and in many areas it is quite true today. The magnetic method has been successfully used in some areas, however, to map features of small areal extent in the sedimentary section, when such features bear a direct relationship to abrupt topography on the basement surface. In areas where depth to the basement is relatively shallow and the lithology and magnetic susceptibility of the granite do not vary laterally, local topography on the basement can often be detected by detailed magnetic surveys. This is especially true in parts of northeastern and northcentral Oklahoma and in adjoining parts of Kansas. A classic example is the Owasso dome, in northern Tulsa County. This feature was surveyed with vertical, horizontal and airborne magnetometers in 1950; an abstract report of the results appears in the Tulsa Geological Society *Digest*, 1955, p. 218-219. This application of the magnetic method has become more and more popular over the past few years and at the present time several major oil companies in Tulsa are conducting close-control ground magnetic surveys in the above-mentioned areas.

In reconnaissance work a magnetic survey is quite useful for delineating the areal extent and approximate depths of sedimentary basins and in detecting other regional trends. It is also useful in mapping igneous intrusions; the approximate shapes and depths of burial of such features can often be calculated. The utility and cost of aeromagnetic surveys has made the airborne magnetometer most useful and adaptable in reconnaissance studies of large land and water areas.

The several versions of the modern airborne magnetometer measure changes in the total field only. A review of the instrumentation, techniques, analysis and interpretation of aeromagnetic surveys may be found in a special issue of *Geophysics*, 1964, Vol. XXIX, No. 4. Most of the issue is devoted to aeromagnetic methods.

## DISCUSSION OF MAGNETIC ANOMALIES IN OKLAHOMA

It should be borne in mind that the magnetic map presented with this issue of the *Proceedings* depicts nothing more than the regional trends, which in many cases bear a direct relationship to known regional geology. It is also noteworthy that there is much correspondence between the regional gravity and magnetic anomalies; many of these have been designated at common locations on each map. It appears, therefore, that regional interpretation of magnetic anomalies in Oklahoma should be made in the light of the related gravity anomalies.

The legend on the magnetic map describes the quality and kind of control for the various areas. Data indicated in the map legend as "taken directly from maps based on detailed vertical-intensity ground surveys" derive from maps which were contoured on a twenty-gamma interval.

The magnetic map of Oklahoma should prove quite useful and beneficial to those conducting close-control ground and airborne magnetic surveys. It will be helpful in planning such programs, and knowledge of the regional picture given by this map may aid in the analysis of local anomalies.

In the following more specific discussions, individual anomalies will be identified by the symbols given on Plate I. In his comments on the gravity anomalies, in the companion paper which follows this one, Paul L. Lyons makes passing reference to some of the same magnetic features.

*P1.* This is the largest regional magnetic anomaly in Oklahoma; it depicts the Wichita Mountains complex. The regional relief is 400-500 gammas, but local anomalies as great as 2,200 gammas are known. The rapid magnetic changes along the flanks of the mountains indicate source rocks at or near the surface, and they reflect the known major flank faulting. Large as some of the local anomalies may be, they are not of sufficient magnitude to suggest any sizeable bodies of commercial magnetite.

*P2.* The second largest magnetic anomaly is coincident with the Arbuckle Mountains. Greatest relief is approximately 500 gammas. Again, no intense anomalies due to magnetite ore bodies appear to be present. The anomaly extends under the Ouachita overthrust system, to the southeast, and may continue on in that direction to link up with *P3*, which corresponds to the core of the Ouachita Mountains. To the northwest, the anomaly extends into Garvin and Grady Counties depicting the Paul's Valley arch. The axis of this feature roughly parallels that of *P1*.

*P3.* This weak anomaly corresponds to the core of the Ouachita Mountains, the Broken Bow-Benton anticline. Its total relief of less than 100 gammas, when compared to the magnitude of the uplift and of the gravity anomaly in the same area, has led to speculation that the Curie point for magnetite may

be exceeded at relatively shallow depths, resulting in a "faded" magnetic anomaly. Known geothermal activity in this region supports this view.

P4. This broad anomaly corresponds to the Osage Island feature, which was an island in early Mississippian time. Although magnetic control in the area is rather limited, some correspondence with the large gravity maximum is indicated.

P5, P6. These maxima are two of a series of magnetic anomalies which lie on the southward extension of the Greenleaf anomaly of Kansas, which is, in turn, a part of the larger Mid-continent gravity and magnetic anomaly that culminates in the Lake Superior graben. This continental feature has been interpreted to be a rift filled with basic igneous rocks high in magnetite content.

P7. This anomaly is interpreted to belong to the P5 and P6 family of anomalies, but now displaced to the west by a basement wrench fault, more fully described in the accompanying gravity paper.

P8. This maximum, the Edmond, appears, like the gravity anomaly, to be associated with the Oklahoma City uplift. The magnetic minimum over the Oklahoma City field appears to be an extension of the minimum N5, and is not easily explained. Elsewhere in Oklahoma some basement uplifts are manifested by negative magnetic anomalies.

P9. This maximum has several culminations which may represent major topographic relief on the basement surface.

P10. This rather low-magnitude anomaly may be reflecting relief on the basement surface.

P11. The Elk City maximum is of deep-seated origin. It is more fully discussed in the companion gravity paper.

P12. The Heavener maximum is likewise of deep-seated origin and, in conjunction with the gravity map, it suggests a batholith.

P13. This anomaly is well defined on both the magnetic and the gravity maps. It is possible that it is associated with some relief on the basement surface; in any case, it indicates a significant lateral change in lithology of the basement rocks.

P14. This anomaly parallels the Arbuckle anomaly. The gravity contours do not close here, but the area is marked by a lobe to the north of the main Arbuckle gravity anomaly. The separation of this magnetic anomaly from the major one over the Arbuckles suggests separate regional geologic features not resolved by the gravity picture. The anomaly shows some correspondence with the Hunton, or Seminole arch, a possible relationship which calls for further study.

P15. The Watonga maximum may be associated with the Greenleaf series of anomalies.

P16. The two Seiling maxima establish a north-south trend in Woodward and Dewey Counties. No corresponding gravity anomaly is known. Forgotson (*Oil and Gas Journal*, March 18, 1963, p. 100-109, Fig. 8), indicates a subsurface anomaly in a computed residual-structure map of this general area.

P17. The Stigler maximum is poorly defined and it has no significant gravity counterpart.

P18. This magnetic maximum could be an extension of P2 or, possibly, of P14.

P19. The Lamont Ring maximum is a more or less circular-shaped anomaly with a ring of culminations around its outer edge. Its diameter is approximately twenty-five miles, it has been speculated that it represents a Precambrian meteorite impact.

P20. This anomaly has an extremely deep-seated source which may be well below "the ancient Archean surface" postulated by Mr. Lyons in the following gravity paper.

N1. The small magnitude of this minimum contrasts with the great gravity negative. This contrast is a further indication of the great thickness of sedimentary fill in this area of Ouachita thrust sheets. The lowest magnetic values are slightly northwest of the lowest gravity values.

N2. Like the gravity minimum, this magnetic feature is an expression of the Ardmore basin.

N3, N4. These minima correspond approximately to the area of greatest deposition for the Anadarko basin. They are separated by the possible Greenleaf anomaly extension P7. In each case, the lowest magnetic values of these two anomalies are south of the lowest gravity values, which further indicates the oneness of these two features, were it not for the interruption of P7.

N5. This anomaly may be related to the minimum N6 in northeastern Oklahoma, but shifted westward by the wrench fault postulated in the following paper.

N6. This poorly-defined minimum does not coincide with any known regional geologic feature.

N7. This minimum corresponds to a gravity minimum. Neither coincides with any known geologic feature; but such local regional geophysical anomalies are common in the Ozark uplift area. Gravity and magnetic maps of Missouri show a number of similar anomalies.

N8. This magnetic feature corresponds to the Mill Creek syncline.

N9. This minimum coincides with a portion of the Nemaha Range, and with a gravity minimum.

N10. This feature, without apparent related gravity or known subsurface anomalies, may result from the lower poles of neighboring magnetic maxima.

N11. Together with the sizeable elongate maxima just to the south, this anomaly indicates an east-west grain which is at odds with the known geologic trends of the area. Basement faulting is suggested.

N12. This minimum does not correspond with any known geologic feature.

#### ACKNOWLEDGMENT

The writer wishes to acknowledge helpful collaboration and discussions with Mr. Paul L. Lyons and with the Editor.



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## GRAVITY MAP OF OKLAHOMA

PAUL L. LYONS

*Sinclair Oil and Gas Co.*

### DEFINITIONS

The gravity map of Oklahoma (Refer to Plate II, in pocket.) portrays the variation in field strength or acceleration of gravity for the State. The unit used is the milligal and the contour interval is five milligals, which gives unusual detail for regional maps of this kind. The reduction formula is the absolute Bouguer; this means, among other things, that all gravity data have been corrected to sea level. In this computation all material between the actual surface and sea level is stripped away. By accepted convention for regional maps, a density of 2.67 grams per cubic centimeter is used for this material. (For oil exploration surveys a local datum other than sea level, and a lower density more representative of the near-surface material, are often used.) Since a density of 2.67 g/cc is too great in areas of thick, relatively light sediments, the net effect of the absolute Bouguer correction is to lower the observed values in such areas, particularly where the elevations are high. Bouguer maps derived in this arbitrary fashion are not always the best for detailed prospecting; but they are a great convenience when data from diverse local surveys are to be combined for a regional picture, and they can be very useful for regional geological interpretation.

The Bouguer correction also takes account of the increase of the acceleration value due to nearer approach to the center of the earth when the observed values are figuratively brought down to sea level. By a latitude formula, decrease northward in distance to the earth's center is corrected, as well as northward decrease in centrifugal force due to the earth's rotation. The map represents the departure of actual gravity values from ideal values for a non-rotating, oblate-spheroidal earth with surface at sea level. These ideal values are given by the so-called International Gravity Formula of 1930. The contour interval, five milligals, is equal to a variation of 5/980,000 of the total acceleration.

The present map is properly termed an *absolute* Bouguer-anomaly map. The basic data for its construction come from field measurements, by pendulum, of the total gravitational force (commonly called absolute gravity measurements), or from conventional gravity meter surveys which have been tied to such absolute measurements. Most modern gravity surveys for the oil industry, especially in North America, are tied to absolute gravity control. However, local Bouguer maps may be referred to an arbitrary gravity datum, for convenience or for lack of pendulum bases, and at no sacrifice to their usefulness in exploration work. Such maps are termed *relative* Bouguer maps.

Derivation of the Bouguer values on Plate II is straightforward. The elevation correction is computed and *added* to the raw gravity measurement. This correction is given by: elevation factor (.06 per foot for density of 2.67 g/cc) x elevation (in feet above sea level). The corrected gravity value is then compared with the theoretical, or ideal, gravity value given for the lati-

tude of the station by the aforementioned International Formula. (See, for example, *Geophysical Prospecting for Oil*, Nettleton, 1940, p. 139-143.) The difference of the corrected from the ideal, plus or minus, is the absolute Bouguer anomaly. This operation can, of course, be carried out in reverse. Starting with the value for one of the reference bases on Plate II, for example, and ascertaining the latitude and elevation, one can calculate the absolute gravity to be expected at the ground surface.

The absolute Bouguer reduction commonly results in negative values for areas, such as Oklahoma, which are located in interior continental positions. Some exceptional plus values indicate emplacement of high-density rocks near the surface, or a thin crust and corresponding high mantle surface. The general westward decrease in the Bouguer values is caused by the isostatic effect of the High Plains and Rocky Mountains which does influence gravity measurements all across Oklahoma. Application of an isostatic correction or reduction to Oklahoma emphasizes the Anadarko basin minimum, since this correction results in a gradual westward increase of the gravity values.

### CONTROL

The kind and quality of control is shown on the legend of Plate II. About 80 per cent of the map is derived from gravity meter work with a high density of stations (averaging six per square mile), and with measurements accurate to 0.1-0.2 milligal. This work, adjusted to a common 2.67 g/cc density correction, has been utilized to determine the 5-milligal contours. The map is also tied to a variety of gravity reference bases. The pendulum stations are those established by the U. S. Coast and Geodetic Survey and they give the absolute value of gravitational acceleration. Although some of these values may be slightly in error, most have been checked and confirmed by high-precision gravity meter runs. The E. V. McCollum & Co. bases are tied to pendulum stations directly or by least square adjustment of networks. They are probably the most accurate absolute measurements available in Oklahoma. Use was also made of stations from the International Gravity Meter Base network established by G. P. Woollard for airports; these values afford an international tie for the map. In addition, the map is compatible with the available data for all surrounding states, and it will presumably tie into national and continental Bouguer-anomaly maps. The reconnaissance stations established by K. L. Cook (density of one or two per township) in the northeastern part of the State, in a USGS-USCGS Survey conducted in 1948, were used for the present map. Originally reduced for a density of 2.57, the data were recalculated for density of 2.67 g/cc. All the data from diverse sources were in remarkable agreement, so that a high degree of confidence can be placed in the map as assembled.

### GENERAL DISCUSSION

The large gravity anomalies on the Oklahoma map afford not only an indication of the rock densities involved in the known regional tectonic features, but also an insight into basement features hitherto unknown or not appreciated. In most cases, confirmation is provided by companion magnetic

features. Actually, a mountain mass or a basin must be defined by its gravity and magnetic anomalies as well as by the observable geologic and seismic expressions. The application of gravity and magnetic interpretations enriches the understanding of these features and aids in their commercial exploration. In the following remarks particular anomalies will be identified, variously, by name and by symbol as given in the "Key to Named Anomalies" on Plates I and II.

P1. This largest maximum in Oklahoma corresponds to the Wichita Mountains. This positive anomaly of more than 50 milligals is coincident with the known surface and subsurface extent of this deeply eroded uplift. Since this is a large mountain mass, one might expect that it is composed of less dense rocks, or that light rocks form a root, so that a regional gravity minimum would result. Instead, the gravity maximum suggests that the uplift is supported by the crust and that isostatic equilibrium has not been attained. It also appears that here a graben or rift feature was filled with basaltic rocks in early Cambrian time and that the graben was converted into a horst block by uplift starting in Pennsylvanian Morrow time.

P2. The second largest maximum is the Arbuckle Mountains. Here again the total gravity relief is of the order of 50 milligals. Gravity decreases sharply on the southwest margin, but less so on the north and west, indicating an intrusion of great areal extent and great depth. The crestal anomaly is split by a minimum corresponding to the Mill Creek syncline. To the northwest, the Paul's Valley arch extension is manifested by an elongate gravity nose. To the north, a gentle nose is roughly coincident with the Hunton, or Seminole, uplift; and to the southeast a connection, extending into Texas, is indicated with the Broken Bow-Benton anticline, P3, which is the crest of Ouachita Mountain uplift.

P3. This maximum, in conjunction with the great minimum N1, marks the gravity expression of the enigmatic Ouachita Mountains. In Oklahoma, the Ouachitas are the culmination of a great inland mountain chain, mostly buried, which parallels the Gulf of Mexico. The maximum marks an uplift of the mantle and crust, and the minimum, which is the most profound such feature east of the Rocky Mountains, marks a depression of the mantle and a thick crust. The gravity picture suggests that this large depression accommodated the great sedimentary thicknesses and subsequent over-thrust sheets which by gravity sliding piled up the present mountain ridges of the Ouachitas.

P4. The Osage Island maximum, centering at Pawhuska in Osage County, is interpreted to be the site of an ancient Precambrian mountain uplift, and of a thinner than normal crust. The anomaly is so named because the area is known to have stood as an island in lower Mississippian time, doubtless due to a rejuvenation of the ancient uplift. The sharp local topographic highs on the basement surface in this area are in great part responsible for the hundreds of overlying drape structures in which the oil accumulations of the Osage country are partially trapped.

P5, P6, P7. These maxima form the Oklahoma extension of the Greenleaf anomaly of Kansas which is, in turn, a part of the Mid-continent gravity

anomaly that culminates in the Lake Superior graben. It has been interpreted in Iowa as a great Precambrian rift filled with flows of basic igneous rocks to a depth of more than six miles. The southward continuation of this major feature is attested by the gravity and magnetic pictures, and there is every reason to expect that the rift is present in the deep rocks of Oklahoma. It appears to extend under the flows of the Wichita Mountains and may be responsible for the curious anomaly in northernmost Tillman County. The eastward extension of P5 may be an ancient meteorite mass, a speculation fortified by the "ring" anomaly designated P19 on the magnetic map.

P8. This maximum, Edmond, appears to be related to the Oklahoma City uplift, which is best established by the patterns of pre-Pennsylvanian sub-crops.

P9. The Rosston maximum, in Harper County, is a low-relief feature which becomes more prominent when the isostatic gradient is removed. It may indicate a Precambrian uplift, which, like the Osage Island, left a number of local topographic highs on the present basement surface.

P10. The Eva maximum is not well defined on the gravity map, but it is probably the density counterpart of the better-defined magnetic maximum.

P11. The same may not be true of the Elk City maximum, which is also well expressed on the magnetic map. The magnetic anomaly may have its origin well within the basement, possibly in Early Precambrian rocks, using the newly adopted nomenclature, or Archean, using the old. This may be related to the early Iron Regime, characterized by free iron in the mantle, many iron-bearing rocks in the crust, and a deficiency of oxygen in the atmosphere. The dense rocks implied at great depth, but above the Curie point for magnetite, may have partly determined the position of the Anadarko basin. By contrast, the gravity effect seems to be minor and of shallow origin; the gravity anomaly is probably associated with overthrusting of Pennsylvanian rocks.

P12. The Heavener maximum is clearly defined by closed contours if the overwhelming regional effect of N1 is removed. It then corresponds to a prominent magnetic anomaly of deep origin. Both anomalies are associated with apparent basement relief which served to influence the position of Ouachita thrust sheets in LeFlore County.

P13. This maximum, the Adams, is much like P9 and is probably related to some basement uplift and relief.

N1. This is the strongest minimum in Oklahoma, already discussed in connection with the Ouachita Mountains. It has about 75 milligals of closure. Its continuation, or counterparts, might be expected to extend all along the buried Ouachita system. In fact, it can be traced only with difficulty, possibly because the less-dense rocks have, in places, approached a limiting high density with burial. The Ouachita system of uplifts, on the other hand, can be followed throughout its extent by gravity maxima such as P3 in southeastern Oklahoma.

N2. This well-defined minimum is indicative of the grabenlike nature of the Ardmore basin. Its prolongation into Bryan County and its tie through Stephens County with the Anadarko basin are clearly shown.

N3. This minimum marks the probable depositional center of the Anadarko basin, if all sedimentary rocks are considered. This minimum would be joined with minimum N4 for the maximum anomaly P7.

N4. This minimum anomaly, the Elk City, marks the approximate center of the Anadarko basin in Pennsylvanian time. The lowest values of the larger regional minimum occur in the Texas Panhandle, augmented by the isostatic effect of the High Plains.

N5. In many respects this Lincoln County minimum is the most difficult to relate to known geologic features. However, correlation of east-west gravity and magnetic profiles would indicate that it is the southern counterpart of minimum N6, and that it has been shifted by a right-lateral or wrench fault in the basement to a location some 40 or 50 miles to the west of its former position. A similar shift is suggested for maximum P7, on the Greenleaf anomaly, which is about 50 miles west of its possible counterpart, P6. The wrench fault in Precambrian rocks may be traced from T14N, R26W eastward to about T17N, R6E. It may be expressed in surface rocks at Guthrie, where an east-west anticline lies south of the fault area; elsewhere the postulated trend is supported by subsurface evidence, implying rejuvenation. At Guthrie, the south side of the interpreted wrench fault is up. The source of anomaly P8 is apparently of later age than that of P6.

N6. This relatively minor feature, the Nowata minimum, may be a secondary effect of the major maximum P4, to the west, which interrupts the western decrease in gravity values. It probably does not have any particular geologic significance.

N7. This minimum, the Hulbert, lies on the southwestern extension of the irregular maximum associated with the Ozark uplift, to the northeast. It has no outstanding significance other than to indicate probable small lateral variation in density of the basement rocks, a phenomenon quite common to the Ozark area, especially in Missouri.

N8. The Mill Creek minimum has been described previously as reflecting a cleft or graben in the Arbuckle Mountain mass; it is marked on the surface by the Mill Creek syncline. The maximum to the north corresponds to the Paul's Valley uplift and its extension to the west.

N9. This minimum coincides approximately with the northern part of a range of basement highs known as the Granite Ridge or the Nemaha Range. This correspondence may be fortuitous, as the minimum does not follow the Ridge along its entire extent. The basement rocks of the Granite Ridge itself do not differ markedly in density or magnetic properties from surrounding rocks, except possibly at maximum P8.

#### COINCIDENCE OF GRAVITY AND MAGNETIC ANOMALIES

There is much correspondence between gravity and magnetic anomalies in Oklahoma. Because of this it has been possible to show symbols at common locations on the gravity and magnetic maps for ready comparison of many of the anomalies. In northeastern Oklahoma, where the basement rocks are rather near the surface, the correspondence of the regional maps is poor. This is to be expected, as the likely sources of both gravity and magnetic effects

are at shallow depths. The resulting anomalies are relatively small in areal extent and hence not well expressed on the present maps. On a local scale, the correspondence of gravity and magnetic anomalies in northeastern Oklahoma is good. (Refer, for example, to the Owasso dome abstract report by V. L. Jones, *Tulsa Geological Society Digest*, 1955, p. 218-219).

The overall correspondence between the gravity and magnetic maps is not fortuitous, even though the two types of anomalies are due to distinctly different rock properties. The intrusive rocks responsible for many of the positive features have both higher magnetite content and greater density. Maximum depths calculated for some of the anomalies, based on their extent and shape, often exceed depths to the basement surface as determined from drilled wells. It is suggested that these calculated depths determine a common surface, the ancient Archean surface, which marks a major Precambrian unconformity. The rocks below this postulated unconformity may have large lateral variations in density and magnetite content.

The regional gravity and magnetic maps for Oklahoma offer unique opportunities for making additional, improved depth estimates and geological interpretations for the deep crust. The inclination of the earth's magnetic field at Oklahoma latitudes causes a shift of the crest of magnetic anomalies as compared to the gravity picture, which is itself an indication of depth of any common source. Further, it appears that both the upper and the lower poles contribute to the magnetic anomalies, affording additional information. The Curie point for magnetite controls the maximum depth for magnetic sources, so that geothermal gradients for local areas may aid interpretation. Unique depth solutions cannot be made in any case, but the variety of data and the geologic limits which can be set will restrict the range of depth, shape, and volume which can be interpreted. A forthcoming paper will deal with depth results for the Oklahoma anomalies.

#### ACKNOWLEDGMENTS

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APPENDIX

GRAVITY BASE STATIONS IN OKLAHOMA

I. U. S. Coast and Geodetic Survey Pendulum Stations

| Number | Location                           | Elevation (ft) | Observed Gravity (gals) | Remarks |
|--------|------------------------------------|----------------|-------------------------|---------|
| 12     | 34°56.2'N;95°45.6'W<br>McAlester   | 787            | 979.636                 | (1)     |
| 100    | 36°40.7'N;101°28.7'W<br>Guymon     | 3113           | 979.5734                | (1) (5) |
| 300    | 34°22.3'N;96°25.4'W<br>Wapanucka   | 634            | 979.6622                | (1) (5) |
| 301    | 34°19.5'N;96°46.9'W<br>Troy        | 926            | 979.662                 | (1)     |
| 302    | 34°13.2'N;97°07.3'W<br>Idle Wilde  | 828            | 979.596                 | (1)     |
| 303    | 34°14.0'N;97°30.6'W<br>Lowery      | 959            | 979.600                 | (1)     |
| 304    | 34°11.3'N;97°32.7'W<br>Carter      | 918            | 979.608                 | (1)     |
| 305    | 34°18.4'N;97°31.6'W<br>Busby       | 1072           | 979.590                 | (1)     |
| 977    | 34°14.7'N;96°12.0'W<br>Caney       | 506            | 979.6426                | (1) (5) |
| 978    | 34°19.8'N;96°11.8'W<br>Tushka      | 634            | 979.6288                | (1) (6) |
| 979    | 34°14.7'N;96°06.6'W<br>Dandridge   | 621            | 979.6152                | (1) (6) |
| 980    | 34°19.5'N;96°05.5'W<br>Atoka       | 629            | 979.6090                | (1) (6) |
| 981    | 34°20.1'N;96°17.4'W<br>Boggy Depot | 534            | 979.6502                | (1) (6) |
| 982    | 34°14.6'N;96°18.2'W<br>Voca        | 693            | 979.6509                | (1) (6) |
| 983    | 34°09.4'N;96°11.9'W<br>Franklin    | 647            | 979.6379                | (1) (6) |
| 984    | 34°09.5'N;96°05.2'W<br>Matoy       | 618            | 979.6166                | (1) (6) |
| 985    | 34°04.2'N;96°05.6'W<br>Banty       | 716            | 979.618                 | (1)     |
| 986    | 34°04.2'N;96°11.5'W<br>Pritchard   | 621            | 979.639                 | (1)     |
| 987    | 34°04.3'N;96°18.1'W<br>Armstrong   | 631            | 979.6401                | (1) (6) |
| 988    | 34°09.4'N;96°17.8'W<br>Caddo       | 658            | 979.6512                | (1) (6) |
| 989    | 34°04.2'N;96°24.6'W<br>Cobb        | 649            | 979.641                 | (1) (6) |
| 990    | 34°09.5'N;96°24.1'W<br>Kenefick    | 651            | 979.6660                | (1) (6) |
| 1136   | 36°01.0'N;95°42.0'W<br>Oneta       | 710            | 979.756                 | (1)     |

| Number | Location                                | Elevation (ft) | Observed Gravity (gals) | Remarks     |
|--------|-----------------------------------------|----------------|-------------------------|-------------|
| 1137   | 36°00.8'N;96°35.5'W<br>Drumright        | 814            | 979.756                 | (1)         |
| 1138   | 36°43.2'N;95°45.3'W<br>Nowata           | 829            | 979.810                 | (1)         |
| 1139   | 35°17.3'N;95°41.5'W<br>Vivian           | 738            | 979.6753                | (1) (5)     |
| 1140   | 35°23.2'N;94°48.8'W<br>Brent            | 519            | 979.705                 | (1)         |
| 1141   | 35°57.2'N;94°42.0'W<br>Proctor          | 809            | 979.752                 | (1)         |
| 1142   | 35°14.7'N;96°34.5'W<br>Seminole         | 953            | 979.681                 | (1)         |
| 1143   | 36°42.2'N;96°41.0'W<br>Burbank          | 1131           | 979.7874                | (1) (5)     |
| 1144   | 36°45.7'N;94°49.6'W<br>Fairland         | 851            | 979.819                 | (1)         |
| 1186   | 34°44.8'N;96°38.7'W<br>Ada              | 845            | 979.672                 | (2)         |
| 1187   | 36°02.4'N;98°57.7'W<br>Taloga           | 1707           | 979.663                 | (2)         |
| 1188   | 36°23.5'N;97°53.5'W<br>Enid             | 1239           | 979.754                 | (2)         |
| 1210   | 36°09.1'N;95°56.5'W<br>Tulsa University | 769            | 979.7653                | (3) (4) (7) |
| 1211   | U. S. Post Office<br>Okmulgee           | —              | 979.7196                | (3) (8)     |
| 1212   | U. S. Post Office<br>McAlester          | —              | 979.6331                | (3) (9)     |

*Remarks:*

- (1) Complete station description given in USCGS Special Publication No. 244, 1949.
- (2) Description for this relatively recent station (1949) available on request to USCGS.
- (3) USCGS "main gravity base station" for Oklahoma (included in USCGS's Mid-Continent Gravity Standardization Range); station description available on request to USCGS.
- (4) In basement of Waite Phillips Engineering Building (Room 7); very near pendulum station GW-51 (in Room 4), of Woollard's International Pendulum Base Net.
- (5) Recently revised gravity value superseding that given in Special Publication No. 244; based on new observations at original pendulum site; subject to further minor adjustment.
- (6) Recently revised gravity value supersedes that given in Special Publication No. 244; based on new observations at gravity mark near original pendulum site; subject to further minor adjustment.
- (7) Descriptions of related gravity meter stations in Tulsa designated "Tulsa 1950" or "Tulsa 2" (at Tulsa University), "Tulsa 3" (at old airport), and "Tulsa 4" (at old airport) available on request to USCGS.
- (8) Description of related gravity meter stations in Okmulgee designated "Okmulgee 1950" (at airport) and "BM Okmulgee 1933 670.084" (at Court House) available on request to USCGS.
- (9) Description of related gravity meter stations in McAlester designated "BM J166 1934" (at U. S. Post Office) and "Pittsburg County Court House" available on request to USCGS.

II. E. V. McCollum & Co. Gravity Meter Base Stations (1)

| Number | Location                            | Elevation (ft) | Observed Gravity (gals) |
|--------|-------------------------------------|----------------|-------------------------|
| 1      | T19N;R12E<br>Sec. 27 ( West Tulsa ) | 693            | 979.7680                |
| 106    | T17N;R10E<br>N.E.Cor.Sec.23         | 804            | 979.7500                |
| 108    | T22N;R13E<br>N.E.Cor.Sec.25         | 654            | 979.7902                |
| 114    | T23N;R5E<br>Sec. 1                  | 795            | 979.7912                |
| 116    | T23N;R7E<br>N.E.Cor.Sec.30          | 822            | 979.7951                |
| 117    | T23N;R8E<br>Sec. 31                 | 1033           | 979.7856                |
| 146    | T16N;R5W<br>Sec. 29                 | 1064           | 979.7212                |
| 147    | T16N;R4W<br>Sec. 10                 | 1022           | 979.7183                |
| 154    | T28N;R4W<br>Sec. 8                  | 1214           | 979.7960                |
| 157    | T26N;R6W<br>Sec. 24                 | 1043           | 979.7979                |
| 158    | T28N;R7W<br>Sec. 22                 | 1164           | 979.8077                |
| 160    | T25N;R8W<br>Sec. 10                 | 1117           | 979.7851                |
| 163    | T25N;R11W<br>N.E.Cor.Sec.10         | 1219           | 979.7664                |
| 165    | T27N;R10W<br>N.E.Cor.Sec.30         | 1160           | 979.7780                |
| 166    | T26N;R12W<br>N.E.Cor.Sec.10         | 1314           | 979.7583                |
| 169    | T27N;R9W<br>N.E.Cor.Sec.21          | 1242           | 979.7823                |
| 170    | T24N;R12W<br>Sec. 35                | 1290           | 979.7510                |
| 175    | T22N;R13W<br>N.E.Cor.Sec.29         | 1361           | 979.7283                |
| 511    | T6S;R8E<br>N.E.Cor.Sec.33(2)        | 745            | 979.5982                |
| 524    | T5N;R23E<br>N.E.Cor.Sec.13          | 2508           | 979.6576                |
| 538    | T1N;R20E<br>S.W.Cor.Sec.32          | 2970           | 979.5789                |
| 540    | T2N;R20E<br>N.E.Cor.Sec.29          | 2759           | 979.6025                |
| 542    | T1N;R22E<br>N.E.Cor.Sec.23          | 2872           | 979.5925                |
| 546    | T3N;R21E<br>N.E.Cor.Sec.35          | 2797           | 979.6101                |
| 552    | T5N;R22E<br>N.E.Cor.Sec.33          | 2660           | 979.6337                |

| Number | Location                   | Elevation (ft) | Observed Gravity (gals) |
|--------|----------------------------|----------------|-------------------------|
| 554    | T5N;R19E<br>N.E.Cor.Sec.36 | 2781           | 979.6205                |
| 556    | T3N;R19E<br>N.E.Cor.Sec.24 | 2747           | 979.6084                |
| 557    | T6N;R21E<br>N.E.Cor.Sec.19 | 2739           | 979.6394                |
| 559    | T6N;R22E<br>N.E.Cor.Sec.28 | 2671           | 979.6470                |
| 560    | T6N;R19E<br>N.E.Cor.Sec.24 | 2845           | 979.6284                |
| 565    | T4N;R23E<br>N.E.Cor.Sec.24 | 2454           | 979.6494                |
| 569    | T3N;R23E<br>N.E.Cor.Sec.36 | 2695           | 979.6226                |
| 574    | T1N;R23E<br>N.E.Cor.Sec.24 | 2812           | 979.5967                |

## Remarks:

- (1) This is a listing of base stations for which complete information is readily available. E. V. McCollum has high-quality observed gravity values at many other identified bases in Oklahoma. A few stations from each category were used in compiling Plate II.
- (2) Value interpolated for this location from contours of Plate II differs from computed Bouguer-anomaly value ( $-18.6$ ) by several milligals. This discrepancy plus other gravity control which became available after map went to press suggests that contours in west-central Bryan County may be in slight error.

## III. International Gravity Meter Bases (Woollard, Airports)

| Number | Location                                                    | Elevation (ft) | Observed Gravity (gals) | Remarks |
|--------|-------------------------------------------------------------|----------------|-------------------------|---------|
| WA53   | 34°55.0'N;95°45.2'W<br>McAlester                            | 750            | 979.6274                | (1) (2) |
| WA54   | 35°23.5'N;97°36.9'W<br>Oklahoma City<br>(Will Rogers Field) | 1283           | 979.6656                | (1)     |
| WA139  | 36°12.2'N;95°54.1'W<br>Tulsa                                | 674            | 979.7766                | (1)     |
| WA254  | 35°25.0'N;97°23.8'W<br>Oklahoma City<br>(Tinker AFB)        | 1291           | 979.6759                | (1) (3) |

## Remarks:

- (1) Station described in *International Gravity Measurements*, by Woollard and Rose 1963, p. 102.
- (2) Geophysical Society of Tulsa compilation gravity map suggests this gravity value in topographical error and that it should read 979.6374.
- (3) Computed Bouguer-anomaly value of  $-27.5$  mgals is not in good agreement with other gravity control nearby. Value shown on Plate II is derived from earlier Woollard station short distance to east (See *Geophysics*, January 1950, p. 23). Note that Bouguer-anomaly given in this reference appears to be in typographical error and should read  $-32.6$ .

IV. International Pendulum Base (George Woollard)

| Number | Location            | Elevation (ft) | Observed Gravity (gals) | Remarks     |
|--------|---------------------|----------------|-------------------------|-------------|
| GW51   | 36°09.1'N;95°56.5'W |                | 979.7655                | (1) (2) (3) |

Remarks:

- (1) Station described in *International Gravity Measurements*, by Woollard and Rose, 1963, pp. 224-5; and in *Proceedings Royal Society of London*, Series A, 1953, v. 219, p. 220.
- (2) Included in Woollard's International Pendulum Base Net.
- (3) In basement of Waite Phillips Engineering Building (Room 4); very near USCGS pendulum station 1210 (in Room 7).

V. Leonard Earth Sciences Laboratory (Jersey Production Research Co.)

| Number | Location              | Elevation (ft) | Observed Gravity (gals) | Remarks |
|--------|-----------------------|----------------|-------------------------|---------|
|        | 35°54'38"N;95°47'33"W | 843            | 979.7356                |         |

OKLAHOMA

J. S. PITTMAN, JR.  
Consulting Geologist  
*Carbonate Petrography and Stratigraphy*  
1101 S. Johnstone  
Bartlesville, Okla. FE 6-2612

TEXAS

W. W. "IKE" NEWTON  
Consultant  
4703 Wildwood Road  
Dallas, Texas 75209 AC 214 - FL 2-0867

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GEOPHYSICAL SOCIETY OF TULSA

PROCEEDINGS

*Principal Business and Titles of Papers Presented*

**October 19, 1961**

S.E.G. Distinguished Lecture: "Reflection Measurements in Gulf of Mexico and Yucatan Basin," Dr. Maurice Ewing, Director of Lamont Geological Laboratory, Columbia University, New York.

Second paper: "Broomstick Distributed Charges," Dr. S. T. Martner.

**November 16, 1961**

Two papers: "Recent Developments in the 'Vibroseis' System," Dr. Milford Lee; and "S.E.G. and the Geophysical Industry," Dr. L. Y. Faust.

**December 11, 1961**

"Changes in the Earth's Magnetic Field," Dr. J. A. Jacobs.

**January 11, 1962**

"The Geological and Seismic Properties of Lake Maracaibo," Mr. Robert A. Kirby and Dr. Franklyn K. Levin, presented jointly.

**February 8, 1962**

Two papers: "Deconvolution and the One-Dimensional Seismogram," Dr. Milo Backus; and "Exploration Activity in Australia," Mr. Hugh M. Thralls.

**March 8, 1962**

Silver Certificates, honoring twenty-five years as members of S.E.G., were presented to: Francis F. Campbell, R. Clare Coffin, Jack R. Cooper, William H. Courtier, John M. Crawford, Clare Hurry, K. M. Lawrence, Paul Lyons, E. V. McCollum, Marvin Romberg, and Loren E. Whitehead. The ceremony was followed by two papers: "A Study of Cased versus Open Holes for Deep-hole Seismic Detectors," Mr. D. R. Van Sandt; and "A Three-Dimensional Seismic Array for Use in Detection of Underground Nuclear Explosives," Mr. R. A. Broding.

**April 12, 1962**

Two papers: "Jersey Production Research Company's Earth Sciences Observatory," Mr. F. G. Boucher; and "Geology and Geophysics of the Arkhoma Basin," Messrs. George Robb, H. M. Thralls, and A. J. Schisler, presented by George Robb.

**May 10, 1962**

Annual Business Meeting, New officers announced. Paper: "Structure of the North Atlantic," Dr. E. Tryggvason, Earth Science Department, Tulsa University.

**October 11, 1962**

S.E.G. Distinguished Lecture: "The Use of Model Studies in Geophysical Exploration," Professor J. M. Bruckshaw, Imperial College, London, England.

**November 8, 1962**

"MURAC—A Multiple Reflection Analog Computer," Dr. Daniel Silverman, Dr. Charles C. Lash, and Dr. Charles F. Hadley, presented by D. Silverman.

**December 13, 1962**

"Oil Exploration from the Research Viewpoint," Mr. James F. Johnson.

**January 10, 1963**

S.E.G. Distinguished Lecture: "Case History of an Exploration Method—Vibroseis," Dr. John Crawford.

**February 14, 1963**

"Computers as Applied to Oil Exploration," Mr. Jack A. Noble.

**March 27, 1963**

Dinner Meeting at Club Tradewinds; "The S.E.G. Foundation," Professor John C. Hollister, President of the S.E.G.

**April 18, 1963**

Meeting held at Continental Oil Company's Research Center, Ponca City; "Experiments in Changing Seismograms to Velocity Logs," Dr. J. P. Lindsey.

**May 9, 1963**

Annual Business Meeting. Announcement of new officers. Presentation of plaques to R. L. Geyer and S. T. Martner as the Best Presentation Award for their Paper "SH Waves from Explosive Sources," given by Geyer at the Research Session of the Annual Meeting of the S.E.G. in Calgary, September 1962. Silver Certificates honoring twenty-five years as members of S.E.G. were presented to: Bruce H. Harlton, W. T. Lea, Ralph Loring, V. A. Peterson, Frank Searcy, Clyde Strachan, Paul Tucker, Stanley Wilcox. The paper for the evening was "Scientific Research," Dr. Norman Ricker.

**September 12, 1963**

Dinner Meeting at the new Sinclair Research Center. Certificates of Merit were presented to G.S.T. past presidents: R. C. Coffin, A. B. Bryan, W. T. Born, H. M. Thralls, R. W. Gemmer, Paul Lyons, Norman Ricker, L. Y. Faust, John Crawford, Bill Erdahl, James F. Johnson, Ted Green, Ralph D. Lynn, James Hawkins, and H. L. Mendenhall. A gavel was presented to President Craig Ferris, and all of the new officers were presented certificates of office. W. B. Brinnon was appointed Vice-Chairman for the Midwestern Regional Meeting in Midland, 1964, and General Chairman for the same meeting to be held in Tulsa, in 1965. Mr. James F. Johnson presented a paper on "The Sinclair Dinoseis System." G.S.T. members were given a conducted tour of the research facilities following the paper.

**October 10, 1963**

"An Optical Correlating Device," Mr. H. S. Field.

**November 21, 1963**

S.E.G. Distinguished Lecture: "The Evolution of Exploration—Continued Development or Regression and Extinction?," Warren Beebe.

**December 12, 1963**

The recommendation of the Executive Committee that G.S.T. incorporate as a non-profit corporation under the laws of the State of Oklahoma was reported to the membership. Copies of the proposed Articles of Incorporation and By-Laws were read and made available to the members. "How to Evaluate

Exploration Prospects," Norman S. Morrisey and Ben Rummerfield, was given by Morrisey.

**January 9, 1964**

The meeting was held at the Sinclair Research Center. The proposal to incorporate was opened for discussion. R. L. Geyer presented the main reasons for incorporating and the content of the Articles of Incorporation. R. A. Brod-ing gave a Treasurer's report that explained why, under the revised by-laws, annual dues were raised to four dollars. The members voted to incorporate and the Executive Committee was directed to apply for incorporation.

The technical program featured a symposium on the future of geophysical exploration. Norman Christie, President of the S.E.G., moderated a panel discussion by five former S.E.G. presidents who are G.S.T. members. The formal presentations were: W. T. Born, "Convolution-Deconvolution and Common Sense"; Andrew Gilmour, "Exploration in Gulf Coast Salt Dome Area"; Paul Lyons, "What's Left to Find?"; E. V. McCollum, "The Status of Exploration Geophysics"; and L. Y. Faust, "Applied Serendipity." After a brief intermission the panel answered questions submitted by the members.

**February 20, 1964**

The meeting was held at the Pan American Petroleum Corporation Research Center. "SADAC—A High-Speed Electronic Digitizing System," Dr. Daniel Silverman and Dr. Charles F. Hadley, was presented by Dr. Silverman. SADAC was demonstrated by Dr. Hadley as a feature of the tour that followed the meeting.

**March 12, 1964**

"Synthetic Velocity Logs" was presented by Dr. D. Y. Kim.

**April 16, 1964**

Silver Certificates honoring twenty-five years as members of the S.E.G. were presented to: Warren A. Alexander, C. E. Buffum, R. C. Clark, Charles E. Day, Karl Dyk, Harry B. Ericson, Craig Ferris, A. V. Hargis, J. E. Hawkins, A. J. Hintze, James S. Hopkins, Roland F. Hughes, P. N. Konkel, Charles C. Lash, Ralph D. Lynn, Waynard B. Perry, Norman Ricker, John J. Rupnik, Richard B. Rutledge, Daniel Silverman, Neil R. Sparks, H. M. Thralls, Byron Vorhies, Kenneth H. Waters, P. S. Williams, James R. Winnek. The paper of the evening: "Some Geometrical Aspects of Multiple Reflection with Inclined Layers which Cause Pseudo Structures," John Bemrose.

**May 14, 1964**

Annual Meeting and First Meeting of the Geophysical Society of Tulsa, Incorporated. The new officers were announced and the paper "Gravity Derivatives and Random Errors," E. V. McCollum, was followed by a movie. "Project Mohole, Phase I," produced by the A.P.I. and narrated by John Steinbeck was presented through the courtesy of Sunray DX Oil Company.

This is the last meeting covered by these *Proceedings* and the Editors would like to add their thanks to those of the Society for the generous refreshments provided at all of the TU meetings by Thralls, Green and Perry.

## OFFICE OF THE SECRETARY OF STATE



## CERTIFICATE OF INCORPORATION

To all to Whom these Presents shall Come, Greetings:

**WHEREAS,** Articles of Incorporation duly signed and verified of

THE GEOPHYSICAL SOCIETY OF TULSA, INC.

have been filed in the office of the Secretary of State on the 8th day of April, A. D. 19 64, as provided by the Laws of the State of Oklahoma.

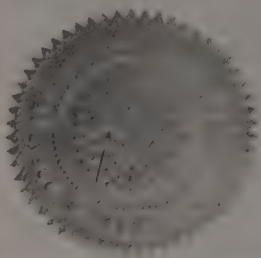
**NOW THEREFORE,** I, the undersigned, Secretary of State of the State of Oklahoma by virtue of the powers vested in me by law, do hereby issue this Certificate of Incorporation.

**IN TESTIMONY WHEREOF,** I haveunto set my hand and cause to be affixed the Great Seal of the State of Oklahoma.

Done at the City of Oklahoma City, this 8 day of April, A. D. 19 64

James M. Bureau  
Secretary of State

By Jane Wetzel  
Assistant Secretary of State



ARTICLES OF INCORPORATION

*The Geophysical Society of Tulsa, Inc.*

ARTICLE ONE

The name of this corporation is: The Geophysical Society of Tulsa, Inc.

ARTICLE TWO

The address of its registered office in the State of Oklahoma is c/o Society of Exploration Geophysicists, Suite 913, Shell Building, Tulsa, Oklahoma, and the name of its Registered Agent at such address is Howard R. Breck.

ARTICLE THREE

The duration of the corporation is Fifty (50) Years.

ARTICLE FOUR

The purpose or purposes for which the corporation is formed are:

A. Educational and Scientific.

B. The further purpose or purposes of the corporation are as follows:

1. To educate and to increase and disseminate the knowledge of the science of geophysics, and the various related physical and earth sciences and mathematics including, but not limited to, geology, electrical or electronic engineering, elasticity and potential field theory.
2. And, incidental thereto, to promote and stimulate interest in geophysics and various related physical and earth sciences, as sciences, and to their study and practice as a profession, and to promote the advancement of geophysics and related physical and earth sciences, in all phases.
3. And, in connection therewith, but not limited to, the following purposes: To conduct special instruction classes for public school teachers and public institutions of all kinds and descriptions; to furnish speakers for public school science classes and other public institutions; to furnish advisors for public school Science Fair projects and to furnish judges for the Science Fair exhibits; to finance and organize and carry out field trips, including, but not limited to, visits to operating geophysical crews or research facilities, for various public and benevolent groups, such as the Boy Scouts of America, and other groups, to make donations to worthy institutions of learning, in connection with the field of geophysics and other related physical and earth sciences, including but not limited to the University of Tulsa, Tulsa, Oklahoma; to obtain, purchase, prepare,

replace, furnish and donate scientific apparatus and equipment, such as used for, but not limited to, geophysical exploration, to worthy institutions of learning, including but not limited to high schools of the Tulsa school system and the University of Tulsa, Tulsa, Oklahoma; to obtain, purchase, prepare, furnish and donate books, maps, documents, charts, pamphlets, publications and other technical matter to the Tulsa Public Library and such other Public Libraries as the Directors may select, and to assist in the organization of the technical section of such libraries, to encourage students of geophysics and other related physical and earth sciences, in institutions of learning, by the awarding of certificates, scholarships, and such other awards as the Directors may designate; to act in an advisory capacity to public institutions of all types and nature; to create, own, operate, contribute to, maintain and administer a separate educational fund, to be utilized for scholarships, research, and such other worthy purposes in connection therewith as the Directors may select, and to accept donations and bequests of all nature for such fund; said scholarships and research to be maintained by either donations or loans from said fund, as the Directors may designate.

4. To organize, supervise, carry out and execute meetings, seminars, scientific assemblies, scientific and educational facilities, field trips generally, exhibitions, museums, libraries and all other media available for the advancement and propagation of the above and foregoing objectives.
5. To promote fellowship among persons interested in the above and foregoing objectives.
6. To cooperate with other similar organizations in accomplishing the above and foregoing objectives.
7. To prepare, edit, print, publish, circulate and distribute various documents, such as, but not limited to: books, charts, maps, pamphlets, periodicals, and diagrams; and to sell and accept advertising therein, all as incidental to and in connection with the above and foregoing purposes.
8. To buy, sell, rent, lease, mortgage and otherwise obtain, deal in or dispose of, on a nonprofit basis, any and all tools, equipment, machinery, supplies and materials, used, obtained, acquired or produced in connection with the above and foregoing objectives.
9. To buy, sell, rent, lease, mortgage and otherwise obtain or dispose of, on a non-profit basis, buses, automobiles, trucks and any and all other media of transportation, reasonably necessary for or incidental to the above and foregoing objectives, and any and all equipment or supplies, for use in connection therewith.
10. To participate in, sponsor, or otherwise share or underwrite the management or expenses of public meetings for scientific and

educational purposes, such as, but not limited to, local, regional or national conventions of worthy organizations having the same or similar purpose or purposes, such as, but not limited to, the Society of Exploration Geophysicists. To prepare, edit, print, publish, circulate and distribute various documents pertaining thereto, such as, but not limited to: meeting notices, programs, and brochures; and to sell and accept advertising therein and to buy, sell, rent, lease, sublease, mortgage and otherwise obtain, deal in or dispose of buildings, rooms, or portions thereof, to exhibitors in connection with said meeting or convention; all as incidental to and in connection with the above and foregoing purposes.

11. To buy, sell, rent, lease, mortgage or otherwise obtain or dispose of, on a nonprofit basis, real property, buildings, fixtures, furniture and appliances, reasonably necessary for or incidental to the above and foregoing purposes.
12. It is the basic purpose and essential nature of this corporation that it is organized and shall be operated exclusively for scientific and educational purposes, and no part of the net earnings nor of the principal shall inure to the benefit of any private shareholder, member, director, or individual; provided, however, that reasonable compensation for personnel or professional services actually rendered as an employee or agent of this corporation, and recompense for actual expenses incurred under authorization of the Board of Directors, may be paid to private individuals; and awards, in the form of scholarships and other forms, may be made to private individuals on a merit basis; and such private individuals shall not be disqualified to receive such compensation and/or recompense, or to receive such awards, by the fact that they are members or Directors of the corporation.
13. To have any and all other powers to do any and all things that are incidental or necessary to, or consistent with the accomplishment of any or all of the foregoing purposes.

#### ARTICLE FIVE

- A. The corporation is not organized for pecuniary profit nor shall have any power to issue certificates of stock or declare dividends, and no part of its net earnings shall inure to the benefit of any member, officer, director, trustees or individual. The balance, if any, of all money received by the corporation from its operations, after the payment in full of all debts and obligations of the corporation of whatsoever kind and nature, shall be used and distributed exclusively for carrying out only the purpose or purposes of the corporation particularly set forth in Article Four hereof.
- B. In the event of the dissolution of this corporation, or in the event it shall cease to carry out the objects and purposes herein set forth, all

the business, property and assets of the corporation shall go and be distributed to such nonprofit corporation of like purpose or purposes as set forth in Article Four, as the Directors of this corporation may select and designate; and in no event shall any of the said assets or property, in the event of dissolution thereof go or be distributed to members, either for the reimbursement of any sum subscribed, donated or contributed by such members, or for any other such purpose.

- C. This corporation is formed exclusively for scientific and educational purposes, and therefore, has no stated capital and no capital stock. Each member of the corporation, except Honorary Members and all other members not fully qualified as Members, shall have one (1) vote in the election of trustees of the corporation. All rights and powers vested in stockholders under the Oklahoma Business Corporation Act (18 O.S. 1961, Secs. 1.1 through 1.250), except those powers and rights that are inconsistent with the purposes of this corporation as set forth in these Articles, shall be vested in the members of the corporation.

## ARTICLE SIX

The number of Directors to be elected at the first meeting of the trustees is: ten (10).

## BY-LAWS

### THE GEOPHYSICAL SOCIETY OF TULSA, INC.

#### ARTICLE I — MEMBERSHIP

1. The members of this Society shall be classified as Members, Life Members, and Honorary Members.

2. Members shall consist of all persons who have heretofore acquired membership in a regular manner, and those persons who shall hereinafter be elected Members as provided. All classes of members shall be entitled to vote and hold elective offices.

3. Applicants for membership shall submit to the Executive Committee an application in writing signed by three sponsors who are members of the Society. By an affirmative vote of six or more members of the Executive Committee an applicant shall be elected to membership.

4. Any person interested in the geophysical profession shall be eligible for membership.

5. The annual dues of members of the Society shall be four dollars (\$4.00) payable in advance on the first day of each calendar year. Members whose applications are approved after July 1 shall be required to pay only one-half of the regular annual dues for the remainder of the first year of membership.

Special assessments may be levied, upon the recommendation of the Executive Committee, by a majority vote of the members present at any regular meeting, provided that the proposal has been moved and discussed at a previous regular meeting and further provided that the recommendation of the Executive Committee be published in the regular meeting notice following the meeting at which the assessment was moved and discussed.

6. Any member may resign from the Society at any time. Such resignation shall be in writing and shall be accepted by the Executive Committee, subject to the payment of all outstanding dues and obligations of the resigning member.

7. Any member who is more than one year in arrears in payment of dues shall be dropped from the Society. Any member, at his own option, may request that he be dropped from the Society and such request shall be granted by the Executive Committee after due notification.

8. Any person who has ceased to be a member under Section 6 or Section 7 of the Article may be reinstated by unanimous vote of the Executive Committee subject to the payment of any outstanding dues and obligations which were incurred prior to the date when he ceased to be a member of the Society.

9. Any member in good standing may become a Life Member by paying a lump sum of Fifty Dollars (\$50.00). Life Members shall receive all publications and meeting announcements of the Society and shall not be required to pay additional annual dues. Life Members, however, shall be required to pay any special assessments levied by the Society.

10. Honorary Members of this Society shall be elected by unanimous vote of the Executive Committee. To be eligible for Honorary Membership, a person must have attained the age of sixty and must have made outstanding contribution or contributions to the geophysical profession in general, or to this Society in particular. Honorary Members shall receive all publications and meeting announcements of the Society but shall not be required to pay dues or any special assessments.

## ARTICLE II – OFFICERS AND EXECUTIVE COMMITTEE

1. The officers of the Society shall be: President, First Vice-President, Second Vice-President, Secretary, Treasurer, and Editor-elect.

2. There shall be district representatives to the Society of Exploration Geophysicists, as provided by the constitution of that society.

3. The Executive Committee shall consist of the Officers, the two most recent available Past Presidents, and the District Representative, or representatives, to the Society of Exploration Geophysicists.

4. The Officers shall be elected by a ballot as hereinafter provided at the Annual Meetings. The President, First Vice-President, Second Vice-President, Secretary, and Treasurer shall serve for one year. The Editor-elect shall serve

for two years, the first year as Assistant Editor and member of the Executive Committee, the second year as Editor.

5. The President shall preside at the meetings of the Society and of the Executive Committee. He shall call special meetings when deemed advisable; shall appoint all committees except as otherwise herein provided; and jointly with the Secretary and Treasurer, shall sign all written contracts and other obligations of the Society. In the temporary absence of other officers, he shall assume their duties or delegate them.

6. The First Vice-President shall be responsible for arranging the technical program of the Society, and shall have the authority to appoint such assistants as he may require. He shall perform the duties of President in the absence or disability of that Officer, and in the event of the President's resignation shall become President for the remainder of the term.

7. The Second Vice-President shall be responsible for arranging entertainment, and shall have the power to appoint members to assist him.

8. The Secretary shall maintain a complete list of the membership of the Society and of its Executive Committee, shall mail advance notice of meetings to all members, shall keep minutes of meetings of the Society, and of its Executive Committee, shall notify the members by mail of proposed amendments to the By-Laws, and shall mail and receive ballots.

The Secretary shall submit to the Secretary-Treasurer of the Society of Exploration Geophysicists a report of each meeting of this Society and of its Executive Committee within two weeks following each such meeting. He shall also submit to the Secretary-Treasurer of the Society of Exploration Geophysicists the names of all Officers and Committee members within two weeks after their election or appointment.

9. The Treasurer shall collect all dues and other obligations to the Society, shall make disbursements authorized by the Executive Committee and shall transact such other business as may be authorized by the Executive Committee. He shall maintain a chronological record of all receipts and expenditures as well as a system of records explaining each expenditure, including evidence of authority to expend funds and evidence of payment. He shall report the condition of the Treasury at each Annual Meeting and at other times upon request of the Executive Committee.

When so instructed by the Executive Committee, he shall make application to the Secretary-Treasurer of the Society of Exploration Geophysicists for such portion of the expenses to be borne by that Society, as may be needed, and shall submit to the Secretary-Treasurer of the Society of Exploration Geophysicists, prior to the annual meeting of that Society, an itemized account of the expenditure of such funds as may have been received from the Society of Exploration Geophysicists during the preceding calendar year.

Prior to the Annual Meeting, the Treasurer shall close his accounts and submit them to a committee of three members of the Executive Committee designated by the President. These members shall audit the cash book.

The new Treasurer shall accept the Society funds by giving an entry to that effect in the cash book.

10. The Editor shall be in charge of the editorial business, shall submit an annual report of such business, shall have authority to solicit papers and material for the regular society publication and for special publications, and may accept or reject material offered for publication. He may appoint editorial assistants.

The Society shall publish a journal. The journal shall be published at intervals designated by the Executive Committee. All reports to the Society by its officers and committees may be published in the journal. Each issue shall contain a membership list. Each issue shall list all committees. Original papers, reviews, abstracts, notes of information deemed by the Editor to be of interest to the members of the Society shall be published in the journal. The Editor shall submit at an early date, for the approval by the Executive Committee, a general outline of the proposed contents of the Proceedings. The Executive Committee may authorize the printing of the journal and may authorize financing and distribution of the journal.

11. The Executive Committee shall transact all business of the Society not otherwise herein specifically provided for. It shall elect all members to the Society, shall authorize all expenditures, shall direct investments of Society funds; shall establish and supervise publications, shall approve and recommend all proposals for special assessments; shall fill vacancies occurring in any office except in the office of President, to which the First Vice-President automatically succeeds, and shall have the power to review all actions and appointments by the Officers.

A quorum of the Executive Committee shall consist of at least four members and approval by at least four members shall be necessary to conduct all business of the Society.

12. The Geophysical Society of Tulsa, Inc., shall be the Tulsa Section of the Society of Exploration Geophysicists.

The District Representatives of the Society of Exploration Geophysicists shall represent the Society and its members at meetings of the Council of the Society of Exploration Geophysicists.

The Officers and the Executive Committee may arrange for the affiliation with other duly organized groups or societies which by object, aims, constitution or practice are aiding, assisting, or developing the profession of geophysics or allied technology.

### ARTICLE III – ELECTION OF OFFICERS

1. A slate of nominees for officers shall be prepared by a Committee on Nominations consisting of the President and the two most recent available Past Presidents. They must secure the consent of all candidates nominated. This slate, of two or more candidates for each office, shall be prepared and announced to the Society at its regular meeting in March of each year.

Additional nominations for each office may be made by written petition of ten or more members in good standing. Such nominations must be submitted to the President not later than the close of the regular meeting in April.

The election of officers shall be by secret mail ballot. The Secretary shall mail to all members, not later than three weeks preceding the Annual Meeting, a ballot listing all candidates properly nominated for each office. Each member voting shall cast one vote for each officer and shall return his ballot to the Secretary in a sealed envelope carrying on the outside his written signature. Only ballots so prepared by members in good standing and received by the Secretary by 4:00 P.M. on the Monday immediately preceding the Annual Meeting shall be valid.

The Secretary shall indicate which ballots are valid and shall deliver them unopened to the Committee on Nominations. The Committee on Nominations shall supervise the counting of ballots prior to the Annual Meeting. The candidates receiving the greatest number of votes cast for an office shall be declared elected to that office. In case of a tie, the Executive Committee shall decide which of the tied candidates shall be elected.

2. The Committee on Nominations shall prepare a slate of nominees for posts of district representatives to the Society of Exploration Geophysicists, which may need to be filled. Additional nominations may be made in manner set forth in Section 1. The election shall be by secret ballot at least three weeks prior to the Annual Meeting of the Society of Exploration Geophysicists.

#### ARTICLE IV – MEETINGS

1. The Annual Meeting shall be held in May of each year, and shall be held on the second Thursday of May, unless otherwise specified by the Executive Committee and due notice given to the membership.

2. The Regular meetings of the Society shall be held on the second Thursday of each month except during the months of June, July, and August, unless otherwise provided by the Executive Committee.

3. Special meetings may be called at any time by the President of the Society.

4. The time and place of regular meetings, the nature of the technical program and the entertainment, shall be determined by the Executive Committee.

#### ARTICLE V – AMENDMENTS

The By-Laws may be amended by a three-fourths vote of the members present at any regular meeting, provided that the proposed amendment has been approved for submittal by the Executive Committee and has been moved at a regular meeting previous to the meeting previous to the meeting at which the ballot shall be taken.

GEOPHYSICAL SOCIETY OF TULSA

ACTIVE MEMBERSHIP ROLL

As of July 15, 1964

**TULSA**

**KARL W. ABEL**  
Mayes-Bevan Co.  
305 Kennedy Bldg.  
Tulsa, Oklahoma

**WARREN A. ALEXANDER**  
Jersey Production Res. Co.  
1133 North Lewis Avenue  
Tulsa 10, Oklahoma

**LEE K. ARNOLD**  
4137 East 42nd Street  
Tulsa 35, Oklahoma

**MAURICE E. ARNOLD, JR.**  
Box 591  
Tulsa 2, Oklahoma

**T. G. ARNOLD**  
3744 East 2nd Place  
Tulsa 12, Oklahoma

**W. H. AUDLEY**  
345 East 29th Place  
Tulsa, Oklahoma 74114

**C. T. AUSTIN**  
Texaco Inc.  
P. O. Box 2420  
Tulsa 1, Oklahoma

**KARL E. BAER**  
3745 East 39th Place  
Tulsa 5, Oklahoma

**GEORGE L. BARNES**  
Box 2040  
Tulsa 2, Oklahoma

**JACK J. BARRY**  
5126 East 21st Street  
Tulsa 14, Oklahoma

**A. J. BARTHELMES**  
4128 South Wheeling  
Tulsa 5, Oklahoma

**BERT L. BASS**  
Texaco Inc.  
P. O. Box 2420  
Tulsa 2, Oklahoma

**JOHN BEMROSE**  
1615 East 31st Place  
Tulsa 5, Oklahoma

**ARTHUR D. BENNETT**  
Pan American Petr. Corp.  
P. O. Box 591  
Tulsa, Oklahoma 74102

**N. JAMES BENTLEY-LLEWELLYN**  
P. O. Box C—Admiral Station  
Tulsa, Oklahoma 74115

**DONALD J. BERG**  
Marathon Oil Company  
P. O. Box 346  
Tulsa, Oklahoma 74101

**MISS LUCILLE BERLIN**  
Supervisor of Science  
3027 South New Haven  
Tulsa, Oklahoma 74114

**T. J. BEVAN**  
Southwestern Computing Service, Inc.  
1631 South Boston  
Tulsa 19, Oklahoma

**C. W. BLAKEY**  
P. O. Box C, Admiral Station  
Tulsa, Oklahoma 74115

**J. R. BLAISDELL**  
Seismograph Service Corp.  
P. O. Box 1590  
Tulsa 1, Oklahoma

**IBREY T. BONNETTE**  
3916 East 1st Street  
Tulsa 12, Oklahoma

**FRANK W. BORMAN**  
Amerada Petroleum Corp.  
Box 2040  
Tulsa 2, Oklahoma

**W. T. BORN**  
136 Mohawk Blvd.  
Tulsa 6, Oklahoma

**F. G. BOUCHER**  
Jersey Production Res. Co.  
1133 North Lewis Avenue  
Tulsa 10, Oklahoma

**CHARLES P. BOWDITCH**  
3424 East 56th Place South  
Tulsa 5, Oklahoma

**D. C. BOWMAN**  
620 S. 91st E. Ave.  
Tulsa 15, Oklahoma

**FRANK BRANISA**  
Jersey Production Res. Company  
1133 North Lewis Avenue  
Tulsa 10, Oklahoma

**HOWARD R. BRECK**  
2912 East 26th Street  
Tulsa 14, Oklahoma

**W. B. BRINNON**  
Box 1650  
Tulsa 2, Oklahoma

**R. A. BRODING**  
2820 E. 39th Street  
Tulsa 5, Oklahoma

**W. M. BROOKS**  
4569 S. Jamestown  
Tulsa 5, Oklahoma

**FRANK E. BROWN**  
P. O. Box 2208  
Tulsa, Oklahoma

**C. E. BUFFUM**  
Pan American Petr. Corp.  
P. O. Box 591  
Tulsa 1, Oklahoma

**ERNEST D. BURKETT**  
Seismograph Service Corp.  
Box 1590  
Tulsa 1, Oklahoma

**K. N. BURNS**  
5910 So. New Haven Street  
Tulsa 35, Oklahoma

**WILLIAM W. BURRESS**  
Sinclair Research Lab  
P. O. Box 3006, Whittier Station  
Tulsa 8, Oklahoma

**FRANCIS F. CAMPBELL**  
Amerada Pet. Corp.  
Box 2040  
Tulsa, Oklahoma

**GERALD L. CANFIELD**  
Amerada Petroleum Corp.  
P. O. Box 2040  
Tulsa 1, Oklahoma

**W. A. CARRUTH**  
Box 2040  
Tulsa, Oklahoma

**J. L. CASEY**  
P. O. Box 1590  
Tulsa, Oklahoma 74101

**DEAN M. CHRISTENSEN**  
1404 East 35th Street  
Tulsa, Oklahoma 74105

**WILLIAM W. CLARK**  
P. O. Box 801  
Tulsa 1, Oklahoma

**DAVID W. COCHRANE**  
Box 1590  
Tulsa 1, Oklahoma

**R. CLARE COFFIN**  
Pan American Petr. Corp.  
P. O. Box 591  
Tulsa 1, Oklahoma

**J. E. CONNELL**  
Box 2040  
Tulsa, Oklahoma

**JACK R. COOPER**  
Pan American Petr. Corp.  
Box 591 (Research Center)  
Tulsa 1, Oklahoma

**D. G. CORBIN**  
Jersey Production Res. Co.  
1133 North Lewis Avenue  
Tulsa 10, Oklahoma

**FLOYD M. CORE**  
Seismograph Service Corp.  
P. O. Box 1590  
Tulsa, Oklahoma 74101

**FRANK G. CORNELL**  
Box 591  
Tulsa 2, Oklahoma

**GARY D. COURTNEY**  
2873 East 45th St. North  
Tulsa 15, Oklahoma

**MARION CRACRAFT**  
The Tulsa Tribune  
Box 1770  
Tulsa 3, Oklahoma

**CLIFTON C. CRAWFORD**  
Amerada Petroleum Corp.  
P. O. Box 2040  
Tulsa 1, Oklahoma

**KENNETH S. CRESSMAN**  
c/o Amerada Petroleum Corp.  
P. O. Box 2040  
Tulsa 2, Oklahoma

**KENNETH C. CRUMRINE**  
Jersey Production Res. Co.  
1133 North Lewis Avenue  
Tulsa 10, Oklahoma

**JOHNNIE C. DAVIS**  
2903 So. Hudson  
Tulsa 14, Oklahoma

**DALLAS R. DAVIS**  
5110 East 15th Street  
Tulsa 12, Oklahoma

**CHARLES E. DAY**  
Geophysical Research Corp.  
136 East Mohawk Blvd.  
Tulsa 6, Oklahoma

**M. E. DAYTON**  
Box 2039  
Tulsa 2, Oklahoma

**K. P. DESAI**  
3715 East 38th Street  
Tulsa, Oklahoma 74135

**RAYMOND G. De VERSE**  
4158 E. 38th St.  
Tulsa 15, Oklahoma

**PARKE A. DICKEY**  
University of Tulsa  
600 South College  
Tulsa 4, Oklahoma

**RONALD E. DIEDERICH**  
Jersey Production Res. Co.  
1133 North Lewis Avenue  
Tulsa 10, Oklahoma

**JOHN W. DUNKIN**  
7110 E. 19th Street  
Tulsa, Oklahoma

**C. P. DURANT**  
4436 East 38th Street  
Tulsa 5, Oklahoma

**KARL DYK**  
Pan American Petr. Corp.  
P. O. Box 591  
Tulsa 1, Oklahoma

**W. H. ELSON, JR.**  
305 Midcontinent Bldg.  
Tulsa 3, Oklahoma

**WILLIAM M. ERDAHL**  
Skelly Oil Co.  
Box 1650  
Tulsa, Oklahoma

**HARRY S. ESHELMAN**  
2448 South Joplin  
Tulsa 14, Oklahoma

**L. Y. FAUST**  
Amerada Pet. Corp.  
Box 2040  
Tulsa, Oklahoma

**RICHARD L. FENTEM**  
P. O. Box 2040  
Tulsa 1, Oklahoma

**JOHN L. FERGUSON**  
3534 S. Zunis Pl.  
Tulsa 5, Oklahoma

**JOSEPH WAVERLY FERGUSON, JR.**  
6558 East 27th Place  
Tulsa 29, Oklahoma

**PAUL M. FERGUSON**  
5406 East 24th Street  
Tulsa 14, Oklahoma

**CRAIG FERRIS**  
1243 E. 28th St.  
Tulsa 5, Oklahoma

**HAROLD S. FIELD**  
Geophysical Research Corp.  
136 Mohawk Boulevard  
Tulsa 6, Oklahoma

**JERRY FILLEBROWN**  
Geophysical Dept.  
Amerada Petroleum Corp.  
Tulsa 3, Oklahoma

**R. K. FINLEY**  
3410 East 58th St.  
Tulsa 35, Oklahoma

**ROBERT S. FINN**  
Seismograph Service Corp.  
P. O. Box 1590  
Tulsa 1, Oklahoma

**J. L. FISHER**  
3318 East King Street  
Tulsa 15, Oklahoma

**ROBERT B. FISHER**  
Davis Equipment, Inc.  
5110 East 15th Street  
Tulsa 12, Oklahoma

**ROBERT D. FORESTER**  
6223 S. Utica Avenue  
Tulsa 5, Oklahoma

**WILLIAM G. FOX**  
1023 West 23rd Street  
Tulsa, Oklahoma 74107

**KENNETH FRAKES**  
Davis Equipment  
5110 East 15th Street  
Tulsa, Oklahoma 74112

**ORVILLE H. FRAZIER**  
Amerada Pet. Corp.  
Box 2040  
Tulsa, Oklahoma

**F. RAY FREEMAN**  
3745 East 3rd Street  
Tulsa 12, Oklahoma

**JACK L. FRIENDLY**  
2621 South Trenton  
Tulsa, Oklahoma 74114

**R. L. FROSSARD**  
Sinclair Oil & Gas Co.  
Box 521  
Tulsa 2, Oklahoma

**NOEL FROST**  
Box 1590  
Tulsa 1, Oklahoma

**SIEGFRIED W. FRUEHLING**  
P. O. Box 1590  
Tulsa 1, Oklahoma

**J. J. FRUGONI**  
1119A North Osage  
Tulsa, Oklahoma 74106

**THOMAS K. FULTON**  
3730 South Winston  
Tulsa 35, Oklahoma

**FRANK J. GARDNER**  
Oil & Gas Journal  
Box 1260  
Tulsa 1, Oklahoma

**J. P. GARNER**  
Tulsa Exploration Co.  
501 Oil Capital Bldg.  
Tulsa, Oklahoma

**JAMES C. GARRIOTT**  
P. O. Box 1590  
Tulsa, Oklahoma 74101

**ROBERT L. GEYER**  
5613 South Pittsburg Ave.  
Tulsa, Oklahoma 74135

**ANDREW GILMOUR**  
4417 So. Lewis  
Tulsa 5, Oklahoma

**S. E. GIULIO**  
Jersey Production Res. Co.  
1133 North Lewis Avenue  
Tulsa 10, Oklahoma

**GEORGE S. GLAZENER**  
Box 2039  
Tulsa 2, Oklahoma

**MILTON D. GOIN**  
7461 East First Street  
Tulsa 12, Oklahoma

**VICTOR V. GRAF**  
Seismograph Service Corp.  
Box 1590  
Tulsa 2, Oklahoma

**G. C. GREEN**  
708 South Sheridan  
Box GG, Admiral Station  
Tulsa, Oklahoma

**JOE W. GREEN**  
P. O. Box 15799  
Admiral Station  
Tulsa 9, Oklahoma

**R. P. GREEN**  
Republic Exploration Co.  
Box 2208  
Tulsa 2, Oklahoma

**T. S. GREEN**  
Geo Prospectors, Inc.  
Box 9577  
Tulsa 7, Oklahoma

**CHARLES F. HADLEY**  
Pan American Petr. Corp.  
P. O. Box 591  
Tulsa 1, Oklahoma

**T. A. HALBROOK**  
3740 East 47th Place  
Tulsa 5, Oklahoma

**J. W. HAMMOND**  
5525 South Toledo Place  
Tulsa 2, Oklahoma

**BRUCE H. HARLTON**  
Harlton Exploration Co.  
Beacon Bldg.  
Tulsa, Oklahoma 74103

**RALPH E. HARTLINE**  
1943 S. College  
Tulsa 4, Oklahoma

**JAMES E. HAWKINS**  
Route 1, Box 363  
Broken Arrow, Oklahoma

**F. M. HAWPE**  
4635 E. 13th Place  
Tulsa 12, Oklahoma

**HAINES C. HIBBARD**  
Jersey Production Res. Co.  
1133 North Lewis Avenue  
Tulsa 10, Oklahoma

**LORIMER W. HOAR**  
4126 E. 35th Pl.  
Tulsa 15, Oklahoma

**JAMES S. HOPKINS**  
Amerada Petroleum Corp.  
P. O. Box 2040  
Tulsa 2, Oklahoma

**JOHN M. HORETH**  
2431 So. Pittsburg  
Tulsa 5, Oklahoma

**A. MAXWELL HOUSE**  
Geo. Prospectors, Inc.  
Box 9577  
Tulsa 7, Oklahoma

**S. GRACE HOWER**  
Amerada Petroleum Corp.  
Box 2040  
Tulsa 2, Oklahoma

**RONALD F. HUGHES**  
Geo. Prospectors, Inc.  
P. O. Box 9577  
Tulsa 7, Oklahoma

**BAYLORA DUKF HULL**  
3030 South Detroit  
Tulsa 14, Oklahoma

**C. R. HUMPHREY**  
3307 South Jamestown  
Tulsa, Oklahoma 74135

**JAMES R. HUNT**  
2140 East 19th Street  
Tulsa 4, Oklahoma

**C. N. HURRY**  
112 East 26th Place  
Tulsa, Oklahoma 74114

**JOHN S. HUTCHISON**  
Jersey Production Res. Co.  
1133 North Lewis Avenue  
Tulsa 10, Oklahoma

**A. E. IBACH**  
Aero Service Corp.  
1401 South Detroit  
Tulsa 20, Oklahoma

**JUDSON G. JACKSON**  
Seismograph Service Corp.  
Box 1590  
Tulsa, Oklahoma

**PETER JACOBSEN, JR.**  
1133 North Lewis Avenue  
Tulsa 10, Oklahoma

**CHET H. JAMESON, JR.**  
414 Enterprise Bldg.  
Tulsa 3, Oklahoma

**R. L. JEFFERIES**  
Union Oil Co. of Calif.  
1812 First Natl. Bank Bldg.  
Tulsa, Oklahoma 74103

**VINCENT F. JENNEMAN**  
P. O. Box 591  
Tulsa 2, Oklahoma

**D. F. JEWELL, JR.**  
6308 East 56th Place  
Tulsa 35, Oklahoma

**JAMES F. JOHNSON**  
Sinclair Res. Labs., Inc.  
Box 3006, Whittier Station  
Tulsa 8, Oklahoma

**JULIUS H. JOHNSON**  
3104 East Latimer Place  
Tulsa 15, Oklahoma

**VIRGIL R. JOHNSON**  
Jersey Production Res. Co.  
1133 North Lewis Avenue  
Tulsa 10, Oklahoma

**R. N. JOLLY**  
7327 Sleepy Hollow Drive  
Tulsa, Oklahoma 74135

**H. JOE JONES**  
Sinclair Research Labs., Inc.  
P. O. Box 7190  
Tulsa, Oklahoma 74105

**V. L. JONES**  
1412 South Norfolk  
Tulsa 20, Oklahoma

**BENNY H. KELLER**  
1412 S. Winston  
Tulsa 12, Oklahoma

**JOHN K. KENTON**  
Pan American Petroleum Corp.  
P. O. Box 591  
Tulsa, Oklahoma 74102

**VERN KIDD**  
P. O. Box 15799  
Admiral Station  
Tulsa 9, Oklahoma

**ROBERT A. KIRBY**  
Jersey Production Res. Co.  
1133 North Lewis Avenue  
Tulsa 10, Oklahoma

**FRANK R. KITTREDGE**  
Sinclair Oil & Gas Co.  
P. O. Box 521  
Tulsa 2, Oklahoma

**A. J. KOCHENDORFER**

Box 1590  
Tulsa 2, Oklahoma

**P. M. KONKEL**

Box 346  
Tulsa 1, Oklahoma

**RALPH A. LANDRUM**

7449 East 30th Street  
Tulsa 14, Oklahoma

**HAROLD M. LANG**

Pan American Petr. Corp.  
P. O. Box 591  
Tulsa 1, Oklahoma

**CHARLES C. LASH**

Pan American Petr. Corp.  
P. O. Box 591  
Tulsa 1, Oklahoma

**FRANKLIN L. LAWRENCE**

7374 East 25th Place  
Tulsa 29, Oklahoma

**HOMER W. LAWRENCE**

Seismograph Service Corp.  
Box 1590  
Tulsa 1, Oklahoma

**K. M. LAWRENCE**

Amerada Pet. Corp.  
Box 2040  
Tulsa, Oklahoma

**FRANKLYN K. LEVIN**

Jersey Production Res. Co.  
1133 North Lewis Avenue  
Tulsa 10, Oklahoma

**E. B. LINDSEY**

Seismograph Service Corp.  
Box 1590  
Tulsa 1, Oklahoma

**HARRY J. LINS**

Seismograph Service Corp.  
Box 1590  
Tulsa 2, Oklahoma

**WILLIAM A. LINTON**

P. O. Box C  
Admiral Station  
Tulsa, Oklahoma

**GEORGE W. LISLE**

4136 South Trenton  
Tulsa 5, Oklahoma

**W. K. LITSON**

Seismograph Service Corp.  
Box 1590  
Tulsa, Oklahoma

**L. F. LOCKARD**

Sinclair Oil & Gas Co.  
Box 521  
Tulsa 2, Oklahoma

**H. A. LUKOWITCH**

Geo. Prospectors, Inc.  
Box 9577  
Tulsa 7, Oklahoma

**RALPH D. LYNN**

Jersey Production Res. Co.  
1133 North Lewis Avenue  
Tulsa 10, Oklahoma

**PAUL L. LYONS**

Sinclair Oil & Gas Co.  
P. O. Box 521  
Tulsa 2, Oklahoma

**T. A. MANHART**

P. O. Box 6216  
Tulsa 17, Oklahoma

**FRANK J. MANTZ**

3726 East 59th Place  
Tulsa 35, Oklahoma

**JAMES L. MARTIN, JR.**

Sinclair Oil & Gas Co.  
P. O. Box 521  
Tulsa 2, Oklahoma

**SAMUEL T. MARTNER**

Pan American Petr. Corp.  
P. O. Box 591  
Tulsa 1, Oklahoma

**R. L. MATHIESON**

807 So. New Haven  
Tulsa, Oklahoma

**THOMAS E. MATSON**

231 E. 20th Street  
Tulsa 20, Oklahoma

**TOM D. MAYES**

Mayes-Bevan Co.  
Kennedy Bldg.  
Tulsa, Oklahoma

**CHARLES D. McALISTER**

1133 North Lewis  
Tulsa 10, Oklahoma

**P. D. McCALMAN**

P. O. Box 1590  
Tulsa, Oklahoma

**ED. R. McCARTER**

5820 East 23rd Street  
Tulsa 14, Oklahoma

**C. W. McCARTY**  
1013 North 68th East Avenue  
Tulsa, Oklahoma 74115

**E. V. McCOLLUM**  
515 Thompson Building  
Tulsa, Oklahoma

**MAX D. McCORMICK**  
2530 South Cincinnati  
Tulsa 14, Oklahoma

**BENJAMIN F. McCOY**  
146 N. Delaware Place  
Tulsa 4, Oklahoma

**LEROY McCRAVEY**  
The Texas Company  
Box 2420  
Tulsa 2, Oklahoma

**CHARLES R. McDONALD**  
Box 591  
Tulsa 1, Oklahoma

**JOSEPH F. MIFSUD**  
Jersey Production Res. Co.  
1133 North Lewis Avenue  
Tulsa 10, Oklahoma

**SHELDON M. MILLER**  
1403 East 5th Court  
Tulsa 20, Oklahoma

**V. K. MILLER**  
5321 So. 33rd W. Ave.  
Tulsa 7, Oklahoma

**W. B. MILLER**  
Geo. Prospectors, Inc.  
P. O. Box 9577  
Tulsa, Oklahoma 74107

**ROBERT G. MILLS**  
Rotary Exploration Co.  
Box 9667  
Tulsa, Oklahoma 74107

**YOUNG O. MITCHELL**  
Tulsa World  
P. O. Box 1170  
Tulsa 2, Oklahoma

**N. C. MOHN**  
5423 South Marion Avenue  
Tulsa 35, Oklahoma

**JOSEPH P. MOLENAAR**  
Sun Oil Company  
P. O. Box 1348  
Tulsa 1, Oklahoma

**N. K. MOODY**  
Seismograph Service Corp.  
Box 1590  
Tulsa 2, Oklahoma

**JAMES M. MOORE**  
P. O. Box 1650  
Tulsa, Oklahoma

**ARNOLD MOOK**  
4917 South Riverside  
Tulsa 5, Oklahoma

**G. ROBERT MORROW**  
Midwestern Instruments, Inc.  
P. O. Box 7509  
Tulsa 9, Oklahoma

**M. E. MORROW**  
Midwestern Instruments  
Box 7509  
Tulsa 9, Oklahoma

**R. W. MOSSMAN**  
Seismograph Service Corp.  
Box 1590  
Tulsa, Oklahoma

**C. S. MOYNIHAN**  
Sun Oil Co.  
P. O. Box 1348  
Tulsa 2, Oklahoma

**BERT F. NALLY, JR.**  
6752 E. Independence St.  
Tulsa, Oklahoma

**I. L. JACK NASH**  
P. O. Box 1590  
Tulsa, Oklahoma 74101

**JAMES R. NEW**  
Consolidated Geophysical Surveys  
212 Court Arcade Bldg.  
Tulsa 3, Oklahoma

**GEORGE R. NEWTON**  
4629 South Jamestown  
Tulsa 5, Oklahoma

**JACK A. NOBLE**  
8507 East 38th St.  
Tulsa, Oklahoma 74145

**JOHN NORRIS**  
1914 South College  
Tulsa 4, Oklahoma

**WALTER O. NOVELLY**  
Republic Exploration Co.  
Box 2208  
Tulsa 1, Oklahoma

**F. EUGENE O'BRIEN**  
Box 346  
Tulsa 1, Oklahoma

**CHARLES W. OLIPHANT**  
1905 Natl. Bank of Tulsa Bldg.  
Tulsa 3, Oklahoma

**JOSEPH O'NEILL**  
Sinclair Research, Inc.  
P. O. Box 7190  
Tulsa, Oklahoma 74105

**J. E. PALMER**  
5341 East 26th Street  
Tulsa 14, Oklahoma

**W. E. PENNINGTON**  
Amerada Petroleum Corp.  
Box 2040  
Tulsa 2, Oklahoma

**C. D. PENTECOST**  
4630 South Columbia Avenue  
Tulsa 5, Oklahoma

**CHARLES C. PERRY, JR.**  
Seismograph Service Corp.  
P. O. Box 1590  
Tulsa 1, Oklahoma

**W. B. PERRY**  
Geo. Prospectors, Inc.  
Box 9577  
Tulsa 7, Oklahoma

**V. A. PETERSON**  
P. O. Box 521  
Tulsa, Oklahoma

**RICHARD D. PITTENGER**  
Jersey Production Res. Co.  
1133 North Lewis  
Tulsa 10, Oklahoma

**JACK W. POE**  
2706 S. Sheridan Road  
Tulsa 14, Oklahoma

**RONALD E. POHLE**  
Marathon Oil Company  
P. O. Box 346  
Tulsa 1, Oklahoma

**DELBERT E. POTTER**  
2814 South Pittsburg  
Tulsa 14, Oklahoma

**NEWELL POTTORF**  
3832 South Victor Avenue  
Tulsa 5, Oklahoma

**B. G. PRESTON**  
Geo. Prospectors, Inc.  
P. O. Box 9577  
Tulsa, Oklahoma

**BENJAMIN F. PROKO**  
5383 E. 27th St.  
Tulsa, Oklahoma

**BOB R. QUALLS**  
Box 9577  
Tulsa 9, Oklahoma

**MARSHALL P. RAGAN**  
1135 South Birmingham  
Tulsa 4, Oklahoma

**DAVID E. REED**  
Box 2239  
Tulsa 1, Oklahoma

**GEORGE W. REED**  
2502 East Admiral Place  
Tulsa 10, Oklahoma

**A. C. REID**  
1718 S. Delaware Pl.  
Tulsa, Oklahoma

**JAMES J. ROARK**  
1218 South Darlington  
Tulsa 4, Oklahoma

**GEORGE L. ROBB**  
4341 E. 28th St.  
Tulsa 14, Oklahoma

**PRICE E. ROBERTS**  
Tulsa Exploration Co., Inc.  
501 Oil Capital Bldg.  
Tulsa 3, Oklahoma

**VAN ROBERTS**  
Box 1590  
Tulsa, Oklahoma

**K. A. ROBERTSON**  
1754 Utica Square, Room 52  
Tulsa 14, Oklahoma

**DONALD J. ROBINSON**  
Jersey Production Res. Co.  
1133 North Lewis Avenue  
Tulsa 10, Oklahoma

**WALTER R. ROBINSON, JR.**  
4191 East 46th St.  
Tulsa 5, Oklahoma

**EDWARD O. ROE**  
3805 E. Independence  
Tulsa 4, Oklahoma

**CLETUS D. ROEMER**  
Consol. Geophysical Surveys  
212 Court Arcade Bldg.  
Tulsa 3, Oklahoma

**ROBERT C. ROESCH**  
Amerada Petroleum Corp.  
Box 2040  
Tulsa 2, Oklahoma

**M. ROMBERG**  
Humble Oil & Refining Co.  
P. O. Box 801  
Tulsa 2, Oklahoma

**DUANE W. ROW**  
4003 East 33rd Street  
Tulsa 35, Oklahoma

**BEN RUMMERFIELD**  
6787 Timberlane Drive  
Tulsa 10, Oklahoma

**JOHN J. RUPNIK**  
730 Beacon Building  
Tulsa 3, Oklahoma

**ROBERT W. SAUBERT**  
Box 1590  
Tulsa 1, Oklahoma

**EDW. G. SCHEMPF**  
1754 Utica Square  
Suite 52  
Tulsa, Oklahoma 74114

**ALVIN J. SCHISLER**  
2431 South Troost  
Tulsa 14, Oklahoma

**S. Wm. SCHOELLHORN**  
Seismograph Service Corp.  
P. O. Box 1590  
Tulsa 1, Oklahoma

**ROBERT J. SHAFER**  
P. O. Box 591  
Tulsa, Oklahoma 74101

**GERALD J. SHIMER**  
Jersey Production Res. Co.  
1133 North Lewis Avenue  
Tulsa 10, Oklahoma

**DANIEL SILVERMAN**  
P. O. Box 591  
Tulsa 1, Oklahoma

**C. F. SIMION**  
6200 E. 41st Street  
P. O. Box 1590  
Tulsa, Oklahoma 74102

**ROBERT L. SIMS**  
5212 E. 20th St.  
Tulsa 12, Oklahoma

**J. D. SKELTON**  
3404 South 93rd East Avenue  
Tulsa, Oklahoma 74145

**CHARLES B. SMITH, JR.**  
1023 W. 23rd St.  
Tulsa 7, Oklahoma

**WARREN H. SMITH**  
Box 2420  
Tulsa 1, Oklahoma

**ALLAN D. SONTAG**  
Jersey Production Res. Co.  
1133 North Lewis Avenue  
Tulsa 10, Oklahoma

**WILLIAM A. SORGE**  
Jersey Production Res. Co.  
1133 North Lewis Avenue  
Tulsa 10, Oklahoma

**TOM F. SOUTHGATE**  
Amerada Pet. Corp.  
Box 2040  
Tulsa, Oklahoma

**SOUTHWESTERN COMPUTING  
SERVICE, INC.**  
1631 South Boston  
Tulsa 19, Oklahoma

**NEIL R. SPARKS**  
Pan American Petr. Corp.  
P. O. Box 591  
Tulsa 1, Oklahoma

**S. T. SPRADLIN**  
Box 346  
Tulsa 1, Oklahoma

**WILLIAM J. STARK**  
2620 East 8th Street  
Tulsa, Oklahoma 74104

**PAUL HARRIS STEED**  
212 Court Arcade Bldg.  
Tulsa 3, Oklahoma

**M. GRADY STEIL**  
P. O. Box 1590  
Tulsa, Oklahoma

**DEAN STOVER**  
Pan American Petr. Corp.  
41st & Yale  
Tulsa 5, Oklahoma

**EDWARD B. STOVER, JR.**  
Box 591  
Tulsa, Oklahoma

**J. M. STRABALA**  
Seismograph Service Corp.  
P. O. Box 1590  
Tulsa, Oklahoma 74102

**PIETER TACKENBERG**  
Cities Service R. & D. Co.  
Box 558  
Tulsa 1, Oklahoma

**ALBERT W. TAYLOR**  
Box 2040  
Tulsa, Oklahoma

**GEORGE T. THOMAS**  
Box 346  
Tulsa 1, Oklahoma

**T. J. THOMAS**  
Sunray Mid-Continent Oil Co.  
P. O. Box 2039  
Tulsa 2, Oklahoma

**H. M. THRALLS**  
Geo. Prospectors, Inc.  
Box 9577  
Tulsa 7, Oklahoma

**KENNETH S. TOWNSEND**  
4406 East 35th Street  
Tulsa 35, Oklahoma

**DONALD J. TRAUBERT**  
8937 East 15th Street  
Tulsa 12, Oklahoma

**PAUL M. TUCKER**  
Humble Oil & Refining Co.  
P. O. Box 801  
Tulsa 2, Oklahoma

**MOURICE D. TURNEY**  
Drawer 1267  
Ponca City, Oklahoma

**RONALD L. ULRICH**  
542 South 105 Place East  
Tulsa 28, Oklahoma

**JERRY E. UPP**  
1548 South College  
Tulsa 4, Oklahoma

**EUGENE USDIN**  
Southwestern Computing Service  
910 S. Boston  
Tulsa 19, Oklahoma

**PETER R. VAIL**  
1133 North Lewis  
Tulsa 10, Oklahoma

**HECTOR A. VAN BUSKIRK**  
2502 East 21st Street  
Tulsa 14, Oklahoma

**W. H. VAN HORN**  
Seismograph Service Corp.  
P. O. Box 1590  
Tulsa 1, Oklahoma

**DONALD R. VAN SANDT**  
1133 North Lewis  
Tulsa 10, Oklahoma

**S. K. VAN STEENBERGH**  
P. O. Box 521  
Tulsa 1, Oklahoma

**STEFAN VON CROY**  
Sunray DX Oil Co.  
P. O. Box 2039  
Tulsa 2, Oklahoma

**H. B. WARREN**  
International Drilling Co.  
314 Enterprise Bldg.  
Tulsa 3, Oklahoma

**B. B. WEATHERBY**  
Box 2040  
Tulsa 2, Oklahoma

**DAVID R. WEICHERT**  
4126 South Columbia Avenue  
Tulsa, Oklahoma 74105

**EDWARD H. WELTSCH**  
4646 East 55th Street  
Tulsa 5, Oklahoma

**G. H. WESTBY**  
Seismograph Service Corp.  
P. O. Box 1590  
Tulsa 1, Oklahoma

**R. O. WHITAKER**  
Skelly Oil Company  
Skelly Building  
Tulsa 19, Oklahoma

**ALAN WHITE**  
c/o The Tulsa Tribune  
P. O. Box 1770  
Tulsa 3, Oklahoma

**STANLEY W. WILCOX**  
1006 East 41st Place  
Tulsa 35, Oklahoma

**LUTHER D. WILLIAMS**  
P. O. Box 2040  
Tulsa, Oklahoma

**P. S. WILLIAMS**  
2619 South St. Louis  
Tulsa 14, Oklahoma

**RILEY WILSON**  
Tulsa World  
315 South Boulder  
Tulsa 3, Oklahoma

**J. R. WINNEK**  
Dayton Exploration Co.  
5730 East Admiral Pl.  
Tulsa 15, Oklahoma

**PHILLIP W. WISE**  
Sinclair Research Labs., Inc.  
Box 3006, Whittier Station  
Tulsa 8, Oklahoma

**RICHARD A. WISE**  
Sunray Mid-Continent Oil Co.  
Box 2039  
Tulsa 2, Oklahoma

**JAMES T. WOODBURN**  
222 South St. Louis Street  
Tulsa, Oklahoma 74120

**RAYMOND C. ZONGKER**  
Ideal Specialty Co.  
2531 E. Independence  
Tulsa 10, Oklahoma

**WILLIAM J. ZWART**  
Box 2040  
Tulsa, Oklahoma

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Phillips Petroleum Co.  
Rm. 824 Frank Phillips Bldg.  
Bartlesville, Oklahoma

**A. C. AUSTIN**  
P. O. Box 1309  
Casper, Wyoming

**JAMES A. BALLARD**  
Cardinal Geophysical Co., Inc.  
822 Union Center  
Wichita, Kansas

**ROBERT W. BALTOSSER**  
1218 East College  
Broken Arrow, Oklahoma

**ROBERT B. BAUM**  
Seismograph Service Corp.  
1229 Texas Nat'l Bank Bldg.  
Houston 2, Texas

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Phillips Petr. Co.  
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Bartlesville, Oklahoma

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Continental Oil Company  
Geophysical Section  
Drawer 1216  
Ponca City, Oklahoma

**DAVID U. BOESCHE**  
404 West Atlanta  
Broken Arrow, Oklahoma

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Bartlesville, Oklahoma

**RICHARD M. BRADLEY**  
International Dept.  
City Service Oil Company  
Bartlesville, Oklahoma

**C. C. BROOKS**  
Box 17  
Marion, Ohio

**GRAYDON L. BROWN**  
2100 John Street  
Ponca City, Oklahoma

**J. W. BURK**  
c/o The Pure Oil Company  
P. O. Box 1611  
Casper, Wyoming

**W. W. BUTLER**  
Tidewater Oil Company  
Box 1404  
Houston 1, Texas

**CITIES SERVICE COMPANY**  
60 Wall Street  
New York 5, New York

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c/o Continental Oil Co.  
Ponca City, Oklahoma

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Bartlesville, Oklahoma

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Bartlesville, Oklahoma

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Development & Research Dept.  
Continental Oil Co.  
Ponca City, Oklahoma

**E. L. CURRENT**  
City Service Oil Company  
Bartlesville, Oklahoma

**E. J. DENADEL**  
Head, Science Department  
College High School  
Bartlesville, Oklahoma

**W. N. DOGGETT**  
Phillips Petr., Co.  
400 W. Frank Phillips Blvd.  
Bartlesville, Ok a.

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Continental Oil Co.  
Drawer 1267  
Ponca City, Oklahoma

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Central High School  
Bartlesville, Oklahoma

**S. D. ELLIOTT**  
Phillips Petr. Co.  
825 Frank Phillips Bldg.  
Bartlesville, Oklahoma

**SHELDON E. ELLIOTT**  
1512 May Lane  
Bartlesville, Oklahoma

**EVERETT L. ERICKSON**  
Continental Oil Company  
P. O. Drawer 1267  
Ponca City, Oklahoma

**HARRY B. ERICSON**  
1538 South Dewey Avenue  
Bartlesville, Oklahoma

**DELBERT W. FAIR**  
417 S. 12th St.  
Ponca City, Oklahoma

**C. M. FERREE**  
1701 Pecan Road  
Ponca City, Oklahoma

**JOHN W. FETROW**  
Geophysical Lab.—Conoco  
Ponca City, Oklahoma

**JOHN V. FRANKLIN**  
The Atlantic Refining Company  
2915 Classen Blvd.  
Oklahoma City 6, Oklahoma

**J. H. FRASHER**  
P. O. Box 35666  
Dallas 35, Texas

**V. U. GAITHER**  
Continental Oil Co.  
Drawer 1267  
Ponca City, Oklahoma

**ROY E. GARTEN, JR.**  
Continental Oil Co.  
Drawer 1267  
Ponca City, Oklahoma

**WAYNE B. GOODENOW**  
1613 El Camino  
Ponca City, Oklahoma

**P. L. GOUPILLAUD**  
209 South 8th Street  
Ponca City, Oklahoma

**M. S. GRAHAM**  
P. O. Box 2212  
Casper, Wyoming

**S. L. GRIMES**  
Phillips Petr. Company  
9 E. W. Frank Phillips  
Bartlesville, Oklahoma

**W. H. GUYTON**  
411 Lannom Building  
122½ Frank Phillips Blvd.  
Bartlesville, Oklahoma

**A. HAIG**  
Phillips Petroleum Company  
402 Bank Bldg.  
Bartlesville, Okla.

**C. E. HALLOCK**  
Phillips Petr. Company  
9 E. W. Frank Phillips Bldg.  
Bartlesville, Oklahoma

**WILLIAM HAMBLETON**  
Department of Geology  
University of Kansas  
Lawrence, Kansas

**SIGMUND HAMMER**  
Gulf Research & Develop Co.  
Box 2038  
Pittsburgh 30, Pennsylvania

**A. V. HARGIS**  
City Service Oil Co.  
Bartlesville, Oklahoma

**BILLY J. HEATH**  
Continental Oil Co.  
Drawer 1267  
Ponca City, Oklahoma

**HARVEY J. HEATON**  
1576 Colorado  
Bartlesville, Oklahoma

**CHARLES F. HINRICHS**  
Phillips Petroleum Co.  
7½ W. W., Frank Phillips Bldg.  
Bartlesville, Oklahoma

**A. J. HINTZE**  
Phillips Petroleum Co.  
621 Frank Phillips Bldg.  
Bartlesville, Oklahoma

**HENRY HOBART, JR.**

Box 1966  
Oil Center Station  
Lafayette, Louisiana

**S. N. HOCKENS**

Phillips Petroleum Co.  
7th Floor A. Bldg.  
Bartlesville, Okla.

**THOMAS P. HUBBARD, JR.**

203 North Weatherred  
Richardson, Texas 75080

**H. R. HUDSON**

Continental Oil Company  
Geophysical Section  
Drawer 1261  
Ponca City, Oklahoma

**JOHN P. HUGHES**

Phillips Petroleum Co.  
9 E. W., Frank Phillips Bldg.  
Bartlesville, Oklahoma

**M. R. HUNDLEY**

Phillips Petroleum Co.  
9 E. W., Frank Phillips Bldg.  
Bartlesville, Oklahoma

**FRANK J. HUSBAND, III**

Phillips Petroleum Co.  
827 Frank Phillips Bldg.  
Bartlesville, Oklahoma

**HARRY C. JOHNSEN**

Phillips Petroleum Co.  
400 West Frank Phillips  
Bartlesville, Oklahoma

**E. W. JOHNSON**

1624 Arbor Drive  
Bartlesville, Oklahoma

**THOMAS E. JOHNSON**

Phillips Petroleum Co.  
829 Frank Phillips Bldg.  
Bartlesville, Okla.

**ELZIE A. KEE**

Phillips Petroleum Company  
821 Frank Phillips Bldg.  
Bartlesville, Oklahoma

**JOSEPH W. KEFFLER**

4004 Harvard  
Bartlesville, Oklahoma

**MAYAN I. KHAN**

Phillips Petroleum Company  
824 Frank Phillips Bldg.  
Bartlesville, Oklahoma

**ALAN H. KWENTUS**

Phillips Petroleum Co.  
829 Frank Phillips Bldg.  
Bartlesville, Oklahoma

**WILLIAM C. LAMB**

Gulf Oil Corp.  
P. O. Box 910  
Coral Gables 34, Florida

**W. T. LEA**

Cities Service Oil Company  
Bartlesville, Oklahoma

**MILFORD R. LEE**

8 Lake Road  
Ponca City, Oklahoma

**J. P. LINDSEY**

Phillips Petroleum Co.  
1107 Keeler  
Bartlesville, Oklahoma

**RALPH C. LORING**

953 Yale Drive  
Bartlesville, Oklahoma

**C. C. LUDWICK**

Shell Oil Company  
1700 Broadway  
Denver 2, Colorado

**J. E. MARITT**

1724 Dewey Avenue  
Bartlesville, Oklahoma

**P. M. McNALLY**

Phillips Petroleum Company  
9 E. W., Frank Phillips Bldg.  
Bartlesville, Okla.

**E. M. McNATT**

Room 2736  
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